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Proceedings of a Symposium on the Equipment/Silviculture Interface in Stand Establishment Research and Operations

R.F. Sutton and L.F. Riley, Editors

Information Report O-X-401
Ontario Region

FORESTRY CANADA, ONTARIO REGION

Ontario Region is one of six regional establishments located across Canada and operated by Forestry Canada. The overall objective of Forestry Canada is to promote the preservation, enhancement and wise use of a healthy, attractive and bountiful forest resource and terrestrial environment for the economic and social benefit of all Canadians. Ontario Region pursues this objective by conducting two major programs: research and technical services and forestry development. Both programs address major problems affecting forest management and the forest environment primarily in Ontario, but because of the transprovincial nature of the forest resource, many elements of our research program are of national significance.

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Major activities in forestry development include federal management responsibility for federal-provincial forest management agreements, participation in the National Forestry Statistics program and forest economics research.

Close working relationships are maintained with the Ontario Ministry of Natural Resources, the forest industry, educational institutions specializing in forestry and the biological sciences, and other forestry organizations within the province. Ontario Region is represented on the Ontario Forestry Council and the Ontario Forestry Research Committee, which have responsibility for coordinating forestry research in Ontario.

It is recognized that forested land must be managed in the best public interest, not only for the wood production essential to our economy, but also for the recreational purposes that are so important to our social well-being. This must be achieved in a manner that will maintain or improve the quality of the forest environment and preserve it for generations to come.

International Union of Forestry Research Organizations

Division 3: Forest Operations and Techniques

S3.02–00 Operational Methods in the Establishment and Treatment of Stands

S3.02–01 Stand Establishment Operations

Proceedings of a Symposium on the Equipment/Silviculture Interface in Stand Establishment Research and Operations

28 September – 03 October 1985

Jasper Park Lodge, Jasper, Alberta, Canada

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1989

Information Report O–X–401

©Minister of Supply and Services Canada 1989
Catalogue No. Fo 46–14/401E
ISBN 0–662–17513–1
ISSN 0832–7122

Copies of this publication are available at no charge from:
Communications Services
Great Lakes Forestry Centre
Forestry Canada, Ontario Region
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Microfiches of this publication may be purchased from:
Micro Media Inc.
Place du Portage
165, Hotel–de–Ville
Hull, Quebec
J8X 3X2

90-04483/3

PREFACE

The S3.02–01 IUFRO **Symposium on the Equipment/Silviculture Interface in Stand Establishment Research and Operations** took place at Jasper Park Lodge, Jasper, Alberta, Canada, from 28 September to 03 October 1985.

The chairman of the organizing committee was Mr. Lorne F. Riley of the Canadian Forestry Service[1], Great Lakes Forestry Centre, Sault Ste. Marie, Ontario. The other members were:

Ms. K. Anderson	Superintendent, Human Resources Services St. Regis (Alberta) Ltd.[2]
Mr. S. Ferdinand	Head, Reforestation Section Alberta Forest Service
Mr. C. H. Geale	Director, Program Support Branch Alberta Forest Service
Mr. R. Gorman	Silviculture Technician, Northern Forestry Centre, Canadian Forestry Service
Mr. B. J. Sutherland	Forestry Officer, Great Lakes Forestry Centre, Canadian Forestry Service
Mr. D. A. Winston	Research Advisor, Forest Renewal, Headquarters, Canadian Forestry Service
Mr. J. C. Wright	Chief Forester, St. Regis (Alberta) Ltd.

The Committee, on its own behalf and on behalf of the International Union of Forestry Research Organizations, acknowledged "with sincere thanks and gratitude" the extensive assistance provided by the Alberta Forest Service, the Canadian Forestry Service, and St. Regis (Alberta) Ltd.: "These agencies have donated staff time, funds and equipment to ensure that everything possible has been done to make the symposium successful."

The original technical program, a registration list, and the current (1989) addresses of authors are appended.

In April 1989, the responsibility for technical editing of the proceedings and preparation of the papers for publication devolved from Lorne Riley to me. Several voluntary papers and posters contributed substantially to the symposium; unfortunately, the files contain no information about them, and only the solicited papers are included in the proceedings. Considerable further delay would have been unavoidable had attempts been made to resurrect the volunteered material.

Even after the prolonged delay that must have seemed unconscionable, the authors cooperated unreservedly to help bring these proceedings to publication. I thank them warmly. I also wish to express my indebtedness to Miss Constance A. Plexman (Chief, Communications Services) and Mr. Geoffrey Hart (Technical Editor), both of Forestry Canada, Ontario Region, Sault Ste. Marie, Ontario, for their support and editorial expertise. The support of Dr. Carl H. Winget (Director General, Forestry Canada, Ontario Region) and Dr. Paul A. Addison (Director, Forest Resources and Environment, Forestry Canada, Ontario Region) is also appreciated.

R.F. Sutton

1. Now Forestry Canada
2. Now Champion International

Between Jasper and Banff, Alberta. 28 September 1985. (Photo by R.F. Sutton)

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KEYNOTE ADDRESS

delivered for

Jean Claude Mercier

Associate Deputy Minister

Canadian Forestry Service[1]

Government of Canada

by

Carl H. Winget

Director General

Research and Technical Services

Canadian Forestry Service[1]

Government of Canada

[1] Now Forestry Canada

As a strong supporter of the International Union of Forestry Research Organizations (IUFRO), I would like to express my appreciation for the opportunity to address this meeting and my hope that IUFRO activities will continue to increase and intensify in North America. It is particularly gratifying to note the strong participation from overseas at this meeting, something which I very much encourage.

The fact that this is the first symposium under IUFRO sponsorship to focus specifically on the equipment/silviculture interface in stand establishment research and operations is somewhat surprising in view of the importance of the subject, but it certainly adds to its appeal and reinforces Canadian Forestry Service interest and participation. We are honored to be one of the sponsors of this discussion of the complex factors affecting reforestation.

Forestry is a major sector of Canada's economy, especially exports, and we obviously have a vested interest in the mechanization of silviculture. With total forest land of more than 4 million km², of which 2.2 million are considered productive and 776,000 ha are harvested annually, large-scale programs of reforestation and stand management are needed to ensure future timber supply. With vast areas of forest, low population density, the continuing migration of workers to urban areas, and high labor costs, mechanization of silviculture will, in the long run, prove essential to effective forest management in Canada. The problem is simply too big to tackle by hand.

Over the last 10 years, our harvesting and regeneration activities have increased considerably. At present, approximately 220,000 ha of land, or about 30% of the area harvested each year, are artificially regenerated. These figures will increase dramatically with new government programs that are now focusing on the need for reforestation. Canadian citizens and politicians have come to realize that forests often do not regenerate by themselves after harvesting and that our economy will suffer drastically in the years to come if we don't act now.

In Canada, we have the rather unusual situation that provinces own 80% of the productive forest land, while only 8% is privately owned, mostly in eastern Canada, and 12% is under federal jurisdiction, mostly in the Northwest and Yukon Territories. The fact that the provinces own most of the resource creates many unique situations in terms of responsibilities and funding of forest regeneration throughout the nation. These, compounded with the size of the country and the varied climate and terrain, offer a tremendous challenge to forest managers.

However, over the last several years, the federal and provincial governments have signed forest renewal agreements totaling more than one billion dollars. These funds are committed to the reforestation of both public and private woodlands, and to the development and application of expertise in intensive forest management. Funds have also been set aside to develop means of increasing silvicultural productivity. Furthermore, the industry is complementing our regeneration efforts through nursery and planting programs in many parts of the country.

Canada is therefore looking forward to rapid growth of reforestation. In view of the very large investments involved, we must ensure that mistakes are minimized, operations are cost-effective, and losses of productive land do not occur. These basic constraints apply, of course, to all nations forecasting major programs of mechanized silviculture.

Unfortunately, although our future requirements for the mechanization of silviculture are considerable, our current capabilities leave much to be desired. Research is being conducted at the Great Lakes Forestry Centre of the Canadian Forestry Service (CFS), where scientists are testing machine capabilities to produce the desired biological results and to meet silvicultural prescriptions set by forest managers. In addition, the Centre maintains an information bank of types of machinery available and coordinates equipment trials and demonstrations throughout the country.

The Forest Engineering Research Institute of Canada (FERIC), which formerly worked only in the areas of harvesting and wood transportation, has now expanded its mandate to include mechanization of silviculture. An agreement was recently signed with the CFS whereby FERIC will be responsible for the design and development of new or improved silvicultural machinery, the evaluation of machine operability, the collection of data on productivity and cost, and the evaluation of machine performance in relation to specific site characteristics. The CFS, through its Great Lakes Forestry Centre, will provide data on post-treatment results, such as quality of tree planting, and the quality and distribution of prepared microsites, concentrating its efforts on the biological aspects of the interface. I am convinced that the establishment of this complementary relationship will prove highly productive.

In addition, some silvicultural equipment has been and is being developed by engineering firms, the forest industry, and provincial governments. The CFS and FERIC are working closely with these agencies to promote the development of a viable silviculture equipment industry in Canada. Although much of the equipment that is in use today is of Scandinavian origin, we have developed some of our own. We pioneered the use of the shark-finned barrel scarifier and developed the Timberland Planter. We are now funding the development of a container seedling planter and a spot scarifier-planter. Some day we may even be able to develop an export market for our machinery.

Most of our attention has been, and still is, focused on reforestation machines and systems. In the future, more attention will have to be given to early stand management, including thinning, pruning, and cleaning. Machines that are cost-effective and maneuverable, and minimize damage to trees and soils, will be needed.

It must be admitted, however, that the use of machinery for silvicultural purposes, including reforestation, is in its infancy in Canada. In most cases, the expected benefits of machines have not been realized, and many machines have found their way to the equipment graveyard, partly because of their inability to deal with difficult terrain, partly because of a lack of proper training for the operators and a lack of attention to matching the prime mover with the silvicultural equipment, but all too often because of biological unsuitability. Such machines obviously must be mechanically efficient and cost effective, but we believe that to be successful and accepted, they must, above all, satisfy biological requirements.

The companion systems to these machines must also accommodate these requirements. For example, it is now recognized that container planting systems such as the Ontario tubeling, though mechanically feasible, are often unsuitable because they do not take biological constraints into account. Much is known of the biological requirements of seedlings and trees, such as the nutrient and moisture demands, the rooting patterns, the effects of different soil characteristics and soil temperatures. Knowledge of these requirements is essential when one is designing mechanical systems for site preparation and planting.

There is also a need for long-term evaluation. For example, mounding with plows was developed to improve soil water regimes and to increase soil temperature. However, a recent evaluation in Finland indicates that Scots pines (*Pinus sylvestris* L.) are experiencing nutritional deficiencies 10 years after planting on such mounds. Evaluations of this kind are necessary for the identification of inappropriate mechanized silvicultural technology with subtle or long-term effects.

The equipment/silviculture interface, which you will explore in this symposium, is a critical one for all countries that foresee a need for mechanized silviculture to deal with large forest

areas, to compensate for scarce or costly labor, or to counteract decreasing forest production. There will be continual conflict between the desire to design simple, robust, affordable machines with the broadest possible range of applications and the need to develop biologically suitable equipment, appropriate for specific uses and ecosystems, that does not damage sites or reduce productive capacity. The resolution of this conflict will require a high degree of creativity and ingenuity. It must draw upon the skills and knowledge of physiologists, ecologists, foresters, and engineers. The successful melding of these talents to combine modern technology and biological imperatives is the challenge you face, a challenge that forest managers around the world are relying on you to meet. In fact, as far as Canada's forest managers are concerned, we cannot afford to see you fail. The consequences would be extremely grave, seriously weakening intensive forest management as an effective forestry strategy.

Consequently, let me say again that Canada is very proud to be hosting this IUFRO meeting. It is one that is especially important and relevant to our expanding reforestation program. I look forward to your presentations and discussions, in the expectation that they will provide insight and direction in an area crucial to the future of forest management in this and many other countries.

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SESSION 1 - ENGINEERING/BIOLOGICAL/OPERATIONAL INTERACTIONS

THE NEED FOR BIOLOGICAL KNOWLEDGE IN THE DEVELOPMENT OF SILVICULTURAL EQUIPMENT

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KEYWORDS: silvicultural equipment, biology, equipment development, planting, site preparation, scarification, stand establishment, mechanized tree planting

INTRODUCTION

By 1986, 100 years will have passed since a Nebraskan farmer, T.A. Stratton, developed the first tree planting machine (Fernow 1889). About 40 years then passed before new attempts were made, also in the United States, to develop tree planting machines (Trenk 1963). In the USSR (Graf Thurn 1943) and Germany (Kmonitzek 1941), the first tree planting machines were developed in the 1930s. But it was after the Second World War that development work in this field really speeded up. Most of the tree planters developed before 1960 were designed for very easy terrain (Bäckström 1977). After 1965, tree planting machines were developed for more difficult terrain conditions, such as clearcut sites with stumps and logging slash.

In other silvicultural fields, also, much development work has been done during the last 25 years. I refer to equipment for scarification, direct seeding, cleaning, thinning, and nursery production. Prime movers with good terrain capabilities, e.g., skidders and forwarders, became common in forestry work about 20 years ago. These kinds of machines were necessary for the further development of silvicultural equipment for rough terrain conditions.

Successful development of a new silvicultural machine almost always requires a joint effort among engineers, biologists, and forest managers. It can also be a joint effort among research organizations (biological and technical, a machine manufacturer, and forest companies or a forest service). This latter type of cooperation has been very common in Sweden. The need for

interaction between engineers and biologists in the development of silvicultural equipment has been stressed by Sirén (1967, 1968) and others.

In Sweden, much has been done in the last 20 years to develop silvicultural equipment for scarification, tree planting, cleaning, and thinning. In this paper I will try to describe the development of scarifiers and tree planting machines with respect to the interaction among industrial engineers, biologists and technicians in research organizations, and company foresters.

SCARIFICATION

Scarification equipment pulled by farm tractors came into use in Swedish forestry early in the 1950s. At that time, prescribed burning and manual scarification were the most common site preparation methods. With the development of forestry tractors, improved scarification equipment was developed for use under rather rough conditions (Rydbo and Talts 1959, Callin and Troëng 1966). Patch scarifiers came into use during the 1960s and, by the end of that decade, Finnish forest plows and forest harrows were being used in Sweden and Finland (Anon. 1970).

Bärring (1965) described some biological effects of manual scalping: planted seedlings exhibited better survival and height increment after scalping, even with small patches. By the end of the 1960s, different ways of improving scarifiers were being considered (Talts 1969).

In 1973, the Forest Operations Institute (then the Logging Research Foundation) and the Department of Silviculture of the Faculty of Forestry, Swedish University of Agricultural Sciences, started a joint effort to study the scalped microsites and the biological results produced by existing scarifiers. The scalps were found to be too small and too few; many seedlings were having to be planted in unscarified ground (Jahnke and Nilsson 1975). Similarly, Söderström (1974) found clear differences in survival and increment among outplants after different methods of soil treatment. He declared that soil treatment was good if it produced:

- increased soil temperature in the rooting zone of seedlings
- microsites that are well drained and free of spring flooding
- high porosity in the rooting zone of seedlings
- protection for seedlings from grass competition
- bare mineral soil around seedlings to inhibit damage by pine weevils.

These considerations led Söderström (1976) to promote planting in mineral mounds in scarified patches.

This technical and biological information was presented to forest managers and manufacturers, and what was required of future scarifiers was specified (Bäckström 1975). Some manufacturers then started intensive development work on soil treatment equipment. During the development work, industrial engineers maintained close contact with biologists and technicians working in research organizations. Technical concepts and biological needs were discussed. The engineers also had contacts with different forest companies and their silvicultural and technical experts.

After 2 years, some new site preparation equipment was developed. For this work, some manufacturers got financial support from various outside sources. The best financial and psychological support, however, was provided by forest companies and the Swedish Forest Service: they bought prototypes or the first units of a new model. Studies of new equipment were also done by at least one company (Edlund 1980).

As new scarification equipment was developed, the Logging Research Foundation and the Department of Silviculture of the Faculty of Forestry studied the new tools and their performance at two sites, one in northern and one in southern Sweden. Technical results were measured and described, and the performance of pine (*Pinus* spp.) seedlings planted on the sites was studied (Berg et al. 1981). The results were compared with the requirements specified on the basis of previous studies (Bäckström 1971, Berg 1978). Some of the new scarifier units met those requirements for difficult terrain. In easy terrain, the results were better than those achieved in difficult terrain, but no equipment met the more stringent requirements for difficult terrain, mostly because of the presence of slash. The technical results obtained with these new units were better than those described by Jahnke and Nilsson (1975). In a special study of two scarification units on difficult terrain, Samuelsson (1981) demonstrated the difficulties of obtaining good results under such circumstances.

The biological results of a study by Berg et al. (1981) confirmed Söderström's (1974, 1976) views on what is required of scarification. The conclusions from that study were that the new scarifiers worked better than the older ones but had to be further improved to give good results even on difficult terrain. The scarifiers also had to be able to make mounds and ridges of mineral soil suitable for planting.

At least two of the scarification units examined in Berg et al.'s (1981) study are no longer made, but some new units, engineered to overcome the problems presented by difficult terrain, are now commercially available.

In the studies mentioned, the effect of scarification on seedling establishment has been examined. But another interesting question is whether various scarification methods have different long-term effects on site index and forest yield. To study this, two field experiments have been established, one in northern and one in southern Sweden. In these experiments, the effects of harrowing, mounding, plowing, and no soil treatment are compared. Both experiments are located on sites with a wide range of site indices, from very dry and poor sites to highly productive sites with good moisture. Experts in soil science, reforestation, and forest yield research are engaged in these experiments. Measurements will be made every fifth year to determine the long-term effects on yield. We will shortly have the results from the first five years of the northern experiments.

Other field experiments to study seedling establishment after different methods of scarification and under different site conditions are also being conducted. For example, the effects of soil type, soil moisture, and climate are being studied. Guidelines for soil treatment on different sites and in different climates are being produced.

In the current biological experiments, very good results have been produced by mounding. The Forest Operations Institute has therefore decided to begin studies to determine the kind of device needed to mound effectively under different terrain conditions.

MECHANIZED TREE PLANTING

The first project to develop tree planting machines for typical Swedish forest terrain was started in 1965. In that project, both seedling production and mechanized planting were emphasized (Sirén 1967, 1968). The prototypes developed in the project were intermittently plowing planting machines that advanced continuously across the terrain. The prototypes were not commercially successful, but there was considerable optimism that it would be possible to develop a tree planter for rather difficult terrain.

In 1970, the Logging Research Foundation decided to design and develop a mechanical tree planter. The technical and biological requirements for such a planter were emphasized from the start (Bäckström 1971), and possible systems for artificial reforestation were analyzed (Bäckström and Wahlqvist 1973). Information from the Sirén project concerning the requirements of tree planting machines in Swedish forestry was provided to forest machine manufacturers. The project initially relied on the same approach that had been used in developing logging machines. Some manufacturers started to work on tree planters, but they soon found this more difficult than producing logging machines. Also, potential profits were rather low. To continue the work, the manufacturers needed financial support.

Tree planters are still being developed in Sweden today. The most advanced machine exists in four prototypes, and a limited number of units is expected to be produced in 1986. The project has been transferred from the original manufacturer to another company. The forest industry and the Swedish Forest Service have supported the manufacturers during the long development period, by buying and/or testing prototypes, or by helping to fund the production of prototypes.

During this period of development, many technical studies have been carried out by the Forest Operations Institute, e.g., simulations of working principles for planting devices, work studies on different prototypes, economic analyses, and studies of the impact of tree planters on the organization of silvicultural work. The results of these studies, and the opportunity to discuss problems and ideas with the people involved in the studies, provided good support to the engineers working on tree planters.

A few rather small biological studies on mechanized tree planting have been carried out during development work. Planting depth, seedling production systems, and survival after mechanized planting have been studied. Also, information about scarification and planting quality from the above-mentioned work on scarifiers has been used in the development of tree planters. But it has become obvious that the technical problems related to tree planter development have been very difficult to solve, and that the engineers have asked for little special biological information.

BIOLOGICAL KNOWLEDGE

The development work on scarifiers and tree planting machines in Sweden since 1965, as described above, has been a joint effort between manufacturers, forest companies, and research organizations, both technical and biological. My experience in biology and technical matters connected with scarification, tree planting, and related problem areas leads me to express the following view on the need for biological knowledge in the development of silvicultural equipment (Fig. 1).

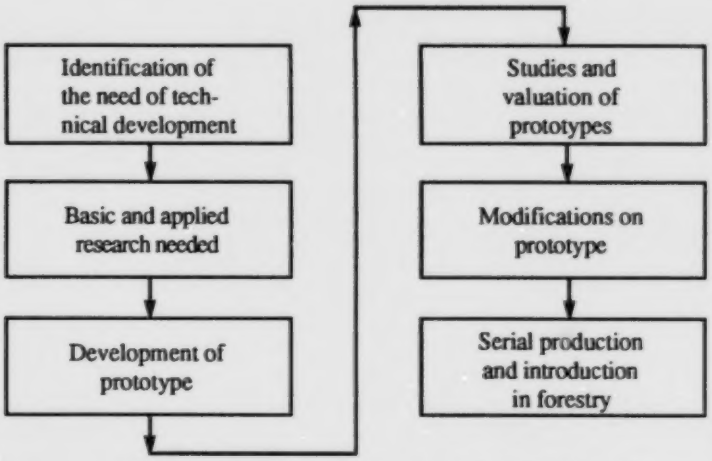
Identification of the need of technical development
Basic and applied research needed
Development of prototype
Studies and valuation of prototypes
Modifications on prototype
Serial production and introduction in forestry

Figure 1. General model for technical development in forestry.

In my opinion, the need for biological knowledge in the development of silvicultural equipment depends on the stage of mechanization reached in a given operation. In the first stage, the main aim is to rationalize manual work to achieve higher productivity and lower unit costs. In this situation, technical solutions are often the main difficulties; usually, the biological knowledge that supports the manual work will be almost sufficient. But the engineer who understands that the machine he is developing must produce good biological results knows that a biologist must be involved. A good biologist can analyze the work, and then give sound advice and encouragement to the engineer. The biologist seldom has time to begin experiments specially designed to produce the perfect answer. Also, the biologist must sometimes be brave enough to estimate and predict biological limits. This he can do better than an engineer. To answer any special questions that the biologist believes will be important in the future, appropriate experiments will be needed as soon as possible, since years must sometimes pass before biological research can produce results.

After a prototype has been developed, its performance, both technical and biological, must be evaluated. At this juncture, the engineer needs answers very quickly. Since biological experiments can seldom provide information quickly enough, the biologist usually has to estimate the biological implications and suggest prototype modification accordingly.

When a new machine comes into serial production and is introduced in forestry, it will be used under a wide variety of site conditions. It is then time to begin studies to determine the operational limitations of the machine. After some years, ideas about a better machine will arise, and the need for further technical development will again be identified. Before development gets under way this time, it is necessary to have a very good understanding of the biological requirements. Biologists are very important links in the development chain.

With respect to the development of a Swedish planting machine, great technical problems are presented by our stony moraine terrain. During the period of development, now almost 15 years, very little specific biological knowledge has been asked for. In the development of scarifiers, however, the situation is different. In 1973, scarifiers were already in use. When the need for technical development was identified, much technical and biological research was carried out before the development work was begun. During development, both kinds of studies were going on. Results were obtained from tests of new equipment on different sites. Now we are attempting to develop better scarifiers or to modify existing scarifiers. Many studies are under way to support future development work. The more advanced the silvicultural machine, the greater the biological knowledge needed to take the next step in the development.

In this paper I have exemplified my points with the development of scarification and mechanized tree planting in Sweden. But I see the same need in the development of machines for thinning and clearing.

CONCLUSIONS

The first time a silvicultural operation is mechanized, the main problems are mostly technical. The need for specific biological knowledge is very low. The more advanced the technical operations become, the more biological knowledge is needed.

During the development of silvicultural equipment, there is often an urgent need for biological information. Technical development usually outpaces the results obtainable from biological studies. The best basis for providing good biological advice for technical development is a thorough knowledge of basic research in forest biology. Biologists can then give advice in advance of any supplementary studies that might be desirable.

In the absence of biological knowledge, the biologist must sometimes be brave enough to estimate biological limitations, because, in general, a biologist can do so better than an engineer.

LITERATURE CITED

Anon. 1970. Suomalaista metsänparannustekniikkaa jakalustoa. Finnish Forest Improvement: Techniques and Machinery. Helsingissä Kustaanusosakeyhtiö, Otava, Helsinki, 131 p. (Bi-lingual Finnish and English)

Bäckström, P.-O. 1971. Biologiska krav vid maskinell plantering. Forskningsstiftelsen Skogsarbeten, **Ekonomi** 5/71, 4 p.

Bäckström, P.-O. and Wahlqvist, Å. 1973. Systems analyses of artificial forest-regeneration. Logging Res. Found., Stockholm, Rep. 1E/73, 87 p.

Bäckström, P.-O. 1975. Markberedning: idag och i framtiden. Forskningsstiftelsen Skogsarbeten, Teknik 8/75, 4 p.

Bäckström, P.-O. 1977. Mechanized planting. Forskningsstiftelsen Skogsarbeten, Meddelande 12, p 103. (Swedish, with English summary).

Bärring, U. 1965. On the importance of scalping and some other problems connected with planting of *Pinus silvestris* L. and *Picea abies* Karst. **Studia Forestalis Suecica** 24: 1-80.

Berg, S. 1978. Krav på markberedningsaggregat. Forskningsstiftelsen Skogsarbeten, Unpublished Paper 1978-08-25.

Berg, S., Bäcke, J. and Jonsson, C. 1981. Markberedningsförsök i Kosta och Bräcke. Forskningsstiftelsen Skogsarbeten, Redogörelse 2/81, 4 p.

Callin, G. and Troëng, I. 1966. The SFI-Scarification. **Studia Forestalis Suecica** 37:1-12.

Edlund, L. 1980. Mineral mound and humus mound methods. p.427-436 *in* Proc. IUFRO 3.02-00 Symposium on Stand Establishment Technique and Technology, Moscow and Riga, September 1979, Moscow.

Fernow, B. E. 1889. Report of the Chief of Forestry Division. p.637-639 *in* 1888 Annual Report, United States Department of Agriculture, Division of Forestry.

Graf Thurn, P. 1943. Forstpflanzmaschinen im Osten. **Forstarchiv** 19:107-108.

Jahnke, B. and Nilsson, G. 1975. Maskinell markberedning: resultat av arbetsstudier. Forskningsstiftelsen Skogsarbeten, Red. 7/75.

Kmonitzek 1941. Die neue Robot-Pflanzmaschine. **Deutsche Forstwirt** 23:408-409.

Rydbo, F. and Taltz, H. 1959. Val av traktor och kultivator vid markberedning. Maskinteknik i jord och skog 5/1959:219-223.

Samuelsson, H. 1981. Konventionella markberedningsaggregat i svår terräng. Forskningsstiftelsen Skogsarbeten, **Ekonomi** 3/81, 4 p.

Sirén, G. 1967. Erfarenheter av maskinell plantering. **Sveriges Skogsvårdsforbunds Tidskrift** 65:318-339.

Sirén, G. 1968. Synpunkter på skogsodlingens mekanisering. **Skogs- o Lantbruksakademiens Tidskrift** 107:271-286.

Söderström, V. 1974. Markberedning. **Sveriges Skogsvårdsförbunds Tidskrift** 72:157-166.

Söderström, V. 1975. Analys av markberedningseffekterna vid plantering på några färska hyggen. **Sveriges Skogsvårdsförbunds Tidskrift** 74:59-333, (English summary).

Talts, H. 1969. Hur kan vi mekanisera hyggesbehandlingen ytterligare? **Sveriges Skogsvårdsförbunds Tidskrift** 67:579-594.

Trenk, F. B. 1963. Evolution of modern tree planting machines. **Journal of Forestry** 61:726-730.

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DEVELOPING A PLANTING MACHINE FOR THE 1990s WITH 1970s' EXPERTISE

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KEYWORDS: planting machines, machine development, automatic planting machine, Multipot™ planting

INTRODUCTION

New systems of reforestation were being developed vigorously in the 1970s, especially in Scandinavia. Nursery techniques were changing; containerized stock was coming into production. Nurseries were increasing in size. New kinds of containers from all over the world were being tested, and new site preparation equipment was being invented. Already by the mid-1970s in Scandinavia, and subsequently in Canada and elsewhere, studies showed that there was a need for improved methods of mechanized planting. At least four or five machines in Sweden, two in Finland, and others in Canada and the Soviet Union, were under development. Huge sums of money were spent, and yet only two projects, both Scandinavian, survived.

So, what went wrong? As we all know, it is easy to be wise after the fact. In this paper I shall try to draw some conclusions from my more than 10 years' experience in planting machine development.

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WHY DID WE START?

The answer is simple: by accident, and on purpose. By accident, because I joined the G. A. Serlachius Corporation in 1974 and became involved with the problem of disposing of huge amounts of waste fiber. On purpose, because the forest industry at that time was diversifying by manufacturing a variety of machines, from pumps to planting machines.

First came the idea of manufacturing modified, chemically treated peat pots. We carried out a worldwide market survey to assess the potential demand for such a product. The results confirmed Professor P-O. Bäckström's earlier conclusion at the Swedish University of Agricultural Sciences in Umeå that there was a definite need not only for pots but also for machines to plant them. The company decided to develop a fully automatic, multifunction planting machine.

We sought to determine:

- the most suitable type of pot
- the most appropriate size of seedling
- the best method of site preparation
- the degree of automation needed
- current reforestation costs and expected future trends
- when the machines would be needed, and in what quantity.

Of the information needed, the easiest to obtain was the estimated future increase in reforestation.

KIND OF POT

As you may remember, several new kinds of container were produced in the early 1970s. One could almost say that the reforestation chief of any reasonably sized forest company wanted to have a container of his own.

We spent quite a lot of time discussing with experts the kind of container we should select. The choice was among paperpots, peat pots, and the Multipot™. At that time, the debate about root development was at its liveliest, and from the biological point of view it would have been very difficult not to choose the peat pot, although we already knew that the Multipot™ would be the easiest to mechanize.

I believe that very few experts at that time would have been willing to advise us to compromise by concentrating on developing a machine for pots already widely used; however, this would have avoided the problem of our having to sell a new pot concept as well as a new machine.

Simultaneous development of a new pot and a new machine also caused another problem: it was sometimes difficult to differentiate the biological results caused by the pot from those caused by the machine.

Lesson number 1: experts are narrow sighted.

SIZE OF SEEDLINGS

I will omit discussion of which species should be planted, and of seedling size differences related to this question.

By the time we started containerization and rationalization, seedling production was at its height. The advice we got was to build the machine to handle small pots (4 x 4 x 7 cm) and seedlings 1 year old or younger. Since we were aiming for the export market, we decided to design for a larger seedling. Today, because of better survival rates and restrictions on herbicides, 2-year-old seedlings seem to be gaining favor.

Lesson number 2: the initiation of a new policy or practice often tends toward extremes.

SITE PREPARATION

We all know that, ideally, methods of site preparation should be tailored to achieve the specific effects required on any given site. We also know of the many different kinds of site preparation equipment that are on the market today. Appropriate site preparation is the basis for good rates of survival among outplants, yet 10 foresters would give 11 different answers to the question: What is appropriate site preparation?

If we had followed the general trend in Scandinavia we would have based our planter on a spot scarifier. But the trend was not strong enough to displace our idea of using a disc scarifier. Development of planting heads was relatively easy; the most expensive part of the machine remains the double-disc hydraulic scarifiers. I am happy to see that others have followed our lead.

Lesson number 3: take a risk and go against a popular trend if it helps to improve the end result.

DEGREE OF AUTOMATION

Automation is most clearly a domain of economists and work study experts. The question of how much automation to provide was, perhaps, the easiest to answer. Of course, we got good advice ranging from "Never in my life will fully automatic machines be needed" to "Design them now". Work safety considerations and cost calculations clearly favored full automation, provided that this had little adverse effect on productivity.

Lesson number 4: talk about money; when we talk about best solutions and what people want, we are full of good ideas, but when we talk about costs, we get a totally different picture.

WHEN AND HOW MANY?

We and others conducted many good studies to estimate the future demand for planting machines. All of the studies showed that machines were needed in the mid-1970s and that market growth would justify the cost of development. How many machines of this kind are in operation today? As far as I know, there are one in Canada, two or three in Sweden, and one in Finland. What happened? I do not know. We still believe that there will eventually be a need for planting machines. In Canada, the need is obvious; how else can all the required planting be done? In Europe, the severe shortage of forest labor forecasted for the 1970s never materialized. However, one can say that we were lucky; if the machines had been needed in the mid-1970s, none would have been ready.

Without a definite market for planting machines, there will soon be no one left to develop them.

Lesson number 5: nothing is more difficult to forecast than the future; the world is changing faster than we in forestry realize.

SUMMARY AND CONCLUSIONS

What did we learn? What would I ask of you as researchers and customers? Not much! Just an answer to a question worth about Can$4 million over a period of 10 years. That is the minimum investment needed for developing a new planting machine.

I would emphasize the following points:

1. When you are asked about your planting machine requirements, ask for an estimate of the length of the development period, then double it before carefully assessing what your needs will be.

2. Because our fields of expertise are becoming increasingly narrow, look around and try to figure out how your field is affected by this development. Discuss it with your colleagues from other fields, including engineering. Change is taking place faster than you think.

3. We need more of these international meetings. Development costs are far too high to justify producing a machine for one country only. An international consensus should be reached. I know this is a lot to ask, but it would be wonderfully helpful to know, for example, that a certain kind of machine could fulfill 30% of a given requirement in country A, 25% in country B, and so on.

4. You are king makers. You can strengthen or weaken a trend. When the experts in a field are too far apart in their thinking, forest owners are confused. This is well exemplified in Finland. You would do well to become more involved in establishing trends. Look at what has happened to herbicide use in Scandinavia! At first, foresters dismissed opposition to herbicides as merely the opinion of a few "radicals". However, public opinion was very quickly influenced by the attacking radicals, with the result that the use of herbicides was banned.

5. When making suggestions, please remember that, although we developers are open-minded, we have behind us those who hold the purse strings. They might see things differently. What you want must be salable.

We who develop new machines can perform minor miracles, but we must follow our employers' directives. The title of my paper expresses the dilemma faced by our team during the process of development. We were lucky we happened to create a machine that, even today, is modern.

In summary:

- to develop a new forestry machine takes from 7 to 10 years;
- the machine must be marketable for at least 7 years to cover the development costs and allow enough time for developing the second generation;
- the machine must be an integral part of an operating system;
- cooperation is needed not only among several companies but also among many experts in different fields;

- reforestation began to develop fast in the 1970s, new container systems around the world became marketable, and there was a strong trend toward rationalizing and mechanizing reforestation;
- this produced a confusing array of different ideas, while foresters could not or would not take a stand;
- attitudes were largely conditioned by the practices of the 1970s;
- all this created a situation in which the developer, in addition to undertaking huge financial risks, had to proceed with development by guesswork.

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CHOOSING THE BEST SILVICULTURAL TOOL FOR THE JOB

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KEYWORDS: regeneration, *Picea glauca*, *Pinus contorta*, site preparation, silviculture, silvicultural equipment, seeding, planting, mechanical site preparation, stand improvement, herbicides, competition, mixedwoods.

INTRODUCTION

When St. Regis (Alberta) Ltd. began operations on its Forest Management Area in 1955, little was known about the silvicultural techniques required to obtain satisfactory regeneration of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*) or white spruce (*Picea glauca* [Moench] Voss var. *albertiana*) in the foothills area of Alberta. The company's first Chief Forester, Des Crossley, had been the Senior Research Officer at the Calgary office of the Canadian Forestry Service and had done considerable research on the regeneration of these species. Here was an opportunity to put some of the results of his research into large-scale field practice.

During the first 10 years of operations, much of the company's forestry effort was directed towards inventorying and mapping its Forest Management Area (FMA) and developing a forest management system suitable for ensuring fulfillment of the company's commitment to sustained yield management. Trials to obtain satisfactory restocking of harvested areas began almost as soon as harvesting started in 1956, and in 1963 a Silviculture Section was established under the Forestry Department to coordinate reforestation activities on the increasing area of cutover lands.

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[1] Chief Forester, retired
[2] Formerly St. Regis (Alberta), Ltd.

To assess the success of the various regeneration practices used, post-harvest surveys, referred to as Management Opportunity Surveys, were initiated in 1965 to record immediately after harvest all pertinent information in each cut block. Previous stand history, and site and slash conditions (including seed availability) after harvest, are recorded, and recommendations are made for post-harvest treatments. This information, initially stored on needle-sort cards, has been computerized since 1972. To this data base for each block is added all subsequent silvicultural information. All applied treatments, as well as the results of all regeneration surveys (conducted 7 years after harvest or 3 years after planting), are noted in the records to form a complete silvicultural history of every block harvested by the company.

Perhaps the computer is one of the most important silvicultural tools we have. This permits us to store all these data for rapid recall and analysis. With this information one can determine the treatments most appropriate for particular forest conditions. It is important that silvicultural treatment decisions be made by knowledgeable, experienced staff; no simple set of rules or guidelines can provide sufficient guidance for prescribing treatments for the variety of situations encountered in the field.

It is tempting to use the computer to determine the treatment to be applied. My preference is to let the computer assist where it can be most useful, i.e., in handling vast amounts of data, and to leave the decision-making to the silviculturist. If we do not develop good practical silviculturists, silvicultural decisions will soon be made by mathematicians and engineers.

In this paper, I have included both equipment and methods under the umbrella of "Silviculture Tools", and I will group the presentation under four main subject headings corresponding to the order in which our company developed its silvicultural practices:

1. site preparation for natural regeneration
2. artificial regeneration - seed and planting
3. mechanical site preparation for artificial reforestation
4. stand improvement.

I. Site Preparation for Natural Regeneration

The agreement between the company and the province of Alberta required that harvested stands be regenerated to acceptable stocking levels within 10 years after harvesting. A knowledge of the history of stand development, and research in harvesting and regeneration techniques on the eastern slopes of the Rocky Mountains, make one thing clear: to establish satisfactory regeneration of white spruce and lodgepole pine within a decade requires the preparation of a receptive seedbed. Company policy is that every hectare that supported a merchantable stand worth harvesting at maturity in the first rotation is also worth regenerating to produce at least as valuable a crop in succeeding rotations.

In the mid-1950s, very little of the available equipment had been designed for forest applications. Consequently, the equipment that was tested in the early years -- including the Fleco rake, brush rakes, V-blades, and the Athens disk -- had been designed for other uses, principally land clearing. By 1957, the decision was made to use the new generation of wide-tracked, high-powered crawler tractors and to develop our own front-mounted blade with scarification teeth to break up the slash and residue, expose mineral soil, and prepare a receptive seedbed.

It was soon noted that, in the very old lodgepole pine stands that were being harvested in some parts of the FMA[3], insufficient cones were being distributed over the exposed mineral soil. This problem was solved by developing an anchor-chain drag for towing behind the scarifying tractor.

Both the scarification plows and the drags underwent several modifications until, about 1965, the present design was adopted. It soon became general practice to use the drags since this gave a neater and more managed look to the blocks. Unfortunately, the drags destroyed the microsites favorable to regeneration of spruce that had been created by the plows, and they exposed too much mineral soil in younger pine stands. Since 1975, the use of the drags has been greatly reduced except in treating the older (> 200 years) pine stands or when filling in abandoned strip roads with pine slash.

Treatment with this equipment has produced satisfactory restocking on about 70% of the area harvested. In certain situations, however, the treatment is ineffective. The first of these is the very moist "deep duff" (up to 60 cm thick) found in the old "climax" spruce-fir stands at high elevations. Furrows made in the heavy slash and duff by the scarification plows frequently failed to penetrate to mineral soil. Even when penetration was achieved, the duff layer commonly fell back into the furrow. In 1965, a program of treatment was begun to compress this deep duff into windrows by angle blading in the spring of the year during snowmelt; at this time, the duff layer can be peeled off down to the still-frozen mineral soil. The treatment can be carried out during a very short period, often no more than a week or two in a year. The treatment is not only costly, therefore, but also inconsistent in quality from year to year.

By the 1970s, other companies and the provincial governments in Canada were becoming involved in reforestation. Interest in the development of equipment designed for reforestation work by both the forest industry and the equipment manufacturers was becoming apparent.

In 1980, the company replaced its angle-blading equipment with the Craig-Simpson rear-mounted ripper plow. This plow had been developed in Alberta for operating in winter as soon as the frozen ground could support the tractor. This not only extended the winter treatment season, but it also reduced the width of the exposed path and, consequently, the width of the intervening windrows. This equipment can also be used on isolated pine blocks to which there is no summer access. In such instances, anchor chains are attached to the hitch on either side of the plow to break up the slash and to distribute cones in the furrow. It is possible to mount two such plows on the parallelogram hitch of a large tractor with about 2-m spacing between. Productivity can be doubled with this arrangement where slash volumes are limited and where slopes are less than 20%.

Another condition that could not be treated satisfactorily with our regular scarification plows was the wet site type supporting lodgepole pine or black spruce (*Picea mariana* [Mill.] B.S.P.); such sites usually had little duff or competing vegetation, but were too wet to support large tractors during the summer months. In the early 1970s, with little success we had experimented with shark-fin barrels and chain drags, primarily in our older "climax" stands. In 1982, we began trials with modified barrels in an attempt to reduce the increasing backlog of these

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[3] Most of the stands being harvested were either climax white spruce and alpine fir (*Abies lasiocarpa* [Hook.] Nutt.) or mature lodgepole pine about 150 years old; the problem stands of lodgepole pine were about 230 years old.

pine/black spruce sites. We found that an acceptable job of site preparation could be done with this equipment and lighter tractors. In 1983, we built two drags incorporating modified barrels. These have been a valuable addition to the expanding arsenal of equipment at our disposal for tackling the difficult job of treating at reasonable cost all of our harvested areas.

The increased interest in silviculture in Canada led to demonstrations of silvicultural equipment at Sault Ste. Marie, Ontario, in 1974, and at Grande Prairie, Alberta, in 1977; the Marttiini plow, Bräcke cultivator, and the TTS disk trencher were observed. The powered disk trenchers, observed in operation in Scandinavia in 1980, were impressive; but, because we lacked suitable towing units, the barrel method remained our best alternative.

While relatively satisfied with the current equipment, all of which can be mounted on or towed behind equipment that is readily available to us, we are always on the lookout for something better. No single piece of equipment appears to be capable of operating satisfactorily in all of the conditions encountered in the forest. Each species, stand condition, soil type, regional climate, and variation in slash and duff conditions provides a new challenge.

2. Artificial regeneration - seeding and planting

A. *Seeding*

From the outset, it was recognized that satisfactory natural regeneration would not be obtained on all areas after harvesting. Therefore, experiments were begun in 1960 to develop seeding and planting techniques that would give satisfactory results in our FMA. Early trials of spot seeding were largely unsuccessful because of losses of seed to rodents and inadequate site preparation. Broadcast seeding, with hand operated Cyclone seeders on scarified blocks, gave rather inconsistent results that were somewhat related to the amount of exposure of mineral soil. With the advent of "blading" in 1965, and the availability of a helicopter, we purchased a Brohm seeder and carried out our first aerial seeding in 1966. Although this seeder was not very reliable, it showed good potential. Since 1966, several thousand hectares have been treated according to this system with a rented aerial seeder. Results have generally been quite good.

B. *Planting*

Disenchanted with the results of plantings in the late 1950s and early 1960s with bare-root stock grown for us by a provincial tree nursery, we began in 1962 to investigate the growing of containerized stock. The company built its first greenhouse in 1965 and produced 0.25 million trees in 3/4-inch (1.9-cm) split-plastic ("Ontario") tubes. This system was readily adaptable to mechanization, both in the greenhouse and in the field, and between 1965 and 1971 more than 6 million tubelings were grown in our nursery and planted on the FMA. The tubelings were planted with a dibble on a variety of sites and seedbed conditions, ranging from untreated and deep duff areas to scarified upland sites. The best growth was obtained when trees were planted in mineral soil, although we do have many excellent plantations where the seedlings were planted directly in the moss. Frost heaving and drought caused heavy mortality, however, and efforts were directed towards developing a container that would encourage better root development, maintain high utilization of greenhouse space, and allow removal of the "plug" before planting, thus eliminating any constraint by the container.

The Spencer-Lemaire Rootrainer© was developed and first used in 1972. To date, approximately 24 million Rootrainer© seedlings have been grown and planted on our cutover areas with the Pottiputki planting tool. A new greenhouse at Hinton, Alberta was brought on stream in 1980; with triple cropping, it has a production capacity of 3 million seedlings per year. It is designed to take advantage of the potential for mechanization associated with the container system.

Trials with mechanical tree planting machines at Hinton have convinced us that, with good site preparation, overall planting production, per person, with a Pottiputki planting tool is almost as high as production with a planting machine. Furthermore, manual planting results in microsite selection of vastly superior quality to that obtained with machine planting. Since there is no shortage of good tree planters to plant container-grown seedlings, which permit an extended planting season, further work on development of mechanical tree planters would appear to be a waste of money.

3. Mechanical site preparation for artificial reforestation

By the mid 1970s, container-grown seedlings were generally performing well on scarified and bladed areas. However, on extremely dry scarified sites, on sites exposed to the prevailing westerly winds, and on sites on which tough sod could not be scalped satisfactorily by hand with mattocks, seedling survival was simply unacceptable. The Bräcke cultivator that we had just seen demonstrated at Sault Ste. Marie, Ontario in 1974 seemed to be the answer on these difficult sites.

Our first Bräcke was acquired in 1976. The unit paid for itself in the first year through reduced planting costs as a result of increased production. Also, seedling survival rates exceeded 90%. The various towing units tried between 1976 and 1978 included the Clark 668 and Timberjack 240D skidders, the F.M.C. tracked forwarder, and a Caterpillar D5 low-pressure tractor. In 1979, we purchased a second Bräcke and two Timberjack 240D skidders. Approximately 85% of our planting sites are now pretreated with these units.

Sites carrying dense hardwood competition could not be treated satisfactorily with the Bräcke and Timberjack 240D skidders. To treat such areas, therefore, we purchased a Cazes and Heppner plow and mounted it on a modified Komatsu D65P tractor. Roughly 10% of our planting sites are prepared with this unit. About 3 years after planting, an application of herbicide is needed to maintain seedling growth potential in the face of the resurgence of shrub and hardwood competition that commonly follows scarification in mixedwoods. This, however, is only a stop-gap measure. We are currently experimenting with site preparation by using a Bräcke equipped with a herbicide applicator 1 year after harvesting and 1 year before planting. If successful, this treatment will reduce greatly, and may eventually obviate, the need for site preparation with the Cazes and Heppner plow.

4. Stand improvement

No discussion of silvicultural tools would be complete without mentioning tending treatments required to maintain acceptable rates of growth throughout the rotation.

Early juvenile spacing efforts in 1962 and 1963 concentrated on manual thinning of dense lodgepole pine that had originated after fire in 1956. Hand-pulling, brush knives, and brush saws were tried. Trials with herbicides, carried out in 1968 and 1969 by the company and the Canadian Forestry Service, involved mostly manual application, but included aerial treatment with Tordon aimed at effecting a degree of thinning and release. The results, assessed in 1971, suggested that manual or mechanical thinning resulted in stronger growth responses than did chemical treatment.

Further tests were carried out with simple brush axes, light-weight chain saws, clearing saws, the Hydro-Ax or Kershaw Klear-way, drum choppers, and bulldozers.

The 1956 burn site was tackled again between 1974 and 1976. Because the accumulation of standing and fallen "brûlé" (fire-killed material) precluded the use of wheeled or tracked equipment, the spacing crews used manual equipment only.

Since by 1976 the cost of spacing fire-origin stands had increased to approximately $1000/ha, we redirected our efforts to the spacing of overstocked regeneration resulting from harvesting and site preparation. There the stocking varied from 2500 to 25,000 stems/ha (in comparison with 25,000 to 150,000 or more in stands of fire origin), and the clearing saw and the Kershaw Klear-way could be used efficiently at a cost of about $250/ha. Trials have demonstrated that, although mechanical thinners show some potential for saving manpower, they do not measurably reduce cost, nor does the mechanical treatment permit good selection of crop trees.

As indicated earlier, the release of conifers from hardwood competition is as important as the spacing of overdense stands. Recent studies have shown that, unless released, many of the coniferous stands regenerated in mixedwood areas will eventually disappear as the coniferous understorey is crowded out by hardwoods or devoured by hares. Past trials involving manual removal of hardwoods with brush saws or "hack-and-squirt" treatment with chemicals have demonstrated that these are not feasible alternatives. Treatment with clearing saws combined with spot applications of herbicides holds promise in special situations. The approval of Roundup© for aerial application has opened the door to practical treatment of these areas; we hope that, before the conclusion of this symposium, our application to treat approximately 60 ha on a trial basis will have been approved by the Alberta Department of the Environment[4].

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[4] The application was turned down.

SUMMARY AND CONCLUSIONS

A wide array of equipment is already available to enable us to perform most of our silvicultural tasks relatively efficiently.

Choosing the right silvicultural tool requires a knowledge of what the tool can be expected to accomplish, the purpose of the treatment, and the factors limiting the application of the equipment to the job. Before advice is sought from the equipment manufacturer, engineer, or biologist, one should find out what tools others in the industry are using in similar situations. If in doubt about the ability of a particular silvicultural tool to perform under certain conditions, see it demonstrated under conditions as similar to those as possible. Never uncritically accept a manufacturer's claims for a piece of equipment!

Several years ago, the Forest Management Group of the Canadian Pulp and Paper Association surveyed its member companies to determine the types and quantities of equipment then in use in forest management and silviculture, the conditions under which each type was being used, and the suitability of the equipment for its purpose. This survey is repeated every 2 years. The results have been made available to the Canadian Forestry Service for inclusion in its data bank of silvicultural equipment. Information exchange and field demonstrations at the Group's annual meetings have been a valuable aid to the forest manager in the pulp and paper industry and, I am sure, directly or indirectly to all forest managers in Canada.

Only recently has interest across Canada in the development and use of specialized silvicultural equipment been sufficient to encourage equipment dealers and developers to become involved. Formerly, most of the silvicultural equipment used in Canada was either developed by the forest industry and the provinces or modified from equipment developed for other purposes.

Experience has shown that no single piece of equipment can be used satisfactorily to treat all, or even several, conditions. Generally, any piece of equipment on the market needs some modification to meet site-specific requirements.

Probably the major consideration in selecting site preparation equipment is that related to the characteristics of the prime mover. This can be a key factor, since the cost of the prime mover is usually more than that of the silvicultural tool itself. In addition to such characteristics as power, traction, mobility, flotation, and size, the availability of the equipment and of parts and maintenance facilities are important considerations. Because of the short season of use for most site-preparation equipment, the prime mover must be either standard equipment within the organization or readily available locally for rent or contract.

Mechanization in silviculture should be attempted only when it can improve treatment quality at a price competitive with that of manual treatments. No mechanization for the sake of mechanization! There is nothing wrong with hiring people; they are usually much more reliable and rewarding to work with than is a piece of machinery.

The forest manager has to solve problems as they occur on a day-to-day basis and accomplish objectives by the most efficient means available. If researchers and equipment developers are prepared to work with the forest manager, who is busy practising silviculture, to improve the efficiency and effectiveness of present practices, their contribution will be welcomed. However, if the researchers and equipment developers are waiting for all the answers before doing anything, the problems will probably have been solved already by the practising forest manager before research is complete.

Restrictions on the use of herbicides to control hardwoods competing with conifers probably constitute the greatest problem facing the forest manager in Canada today. I am sure this problem is not confined to Canada. We are battling an opposition that is usually based in urban centers remote from the forest areas in question, has a misguided perception of the effects of our forest management practices, and either fails to recognize or chooses to disregard the impact that the forest products industry has on Canada's, and its own, economic and social well being. If we lose this battle, we will waste a lot of time, effort, and money, trying to reforest many of our most productive sites. Many of our present mixedwood stands will convert to pure hardwoods after harvest if herbicide treatment for coniferous tending is not permitted. Utilizing hardwoods is not the answer, since much of this material is of low quality; we have to **control** the hardwoods.

The argument presented in this paper is that, to reforest harvested areas successfully, we must employ the silvicultural tools and techniques best suited to the requirements of the given area and species. Once established, the new crop needs to be tended throughout the rotation to ensure the optimum harvestable crop in the subsequent rotation. If necessary, approved herbicides will be used to control competing vegetation in the early stages of stand development. Doing half the job, i.e., obtaining a satisfactory amount of regeneration, is not good enough!

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DEVELOPMENT OF SILVICULTURAL EQUIPMENT IN NEW ZEALAND

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and

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KEYWORDS: silviculture, machinery, equipment, forest management, New Zealand

INTRODUCTION

The forest industry in New Zealand has established an effective organizational structure for developing silvicultural equipment. In New Zealand, "silviculture" encompasses forest operations from seed collection through pruning and precommercial thinning, but excludes logging.

The nature of forest operations is defined by three primary constraints:

1. Product requirements. From our plantations we wish to obtain a range of different products, including lumber of various dimensions, wood chips, and veneers. Ideally, these products should be obtainable as soon and as cheaply as possible.

2. Biological/environmental constraints. Trees take time to grow, and they vary in dimensions. Processing costs vary with dimensions. Both dimensions and growth rates are affected by site quality and genotype.

3. Ergonomic/mechanical constraints. Work is required to organize the plants and the environment to yield the desired products; this work has both financial and mechanical limitations. For example, positive growth responses among trees planted on compact pumice soils are obtained after site preparation by ripping to a depth of 60 cm; this depth is determined not by the response of the trees, but by the prohibitive expense of ripping more deeply.

The objective of equipment development is to reduce ergonomic and mechanical constraints, and increase the efficiency of forest operations. No one individual has experience in all the many disciplines required to achieve this; a multi-disciplinary team is required (Brown et al. 1982). The team must take direction from a well informed funding body. At the Forest Research Institute (FRI), these two bodies are the **Silvicultural Equipment Research Group** (SERG) and the **Silvicultural Equipment Development Committee** (SEDC), respectively.

This paper uses examples from the authors' experience to describe the organization of silvicultural equipment development at FRI. The steps required for development are discussed, and the organization that satisfies these requirements is described. In addition, some projects in which SERG has been involved are outlined.

STEPS IN THE DEVELOPMENT OF EQUIPMENT

Initiation and control of development

Developers must ensure that their resources are used on the right projects. Three factors must be considered:

1. Benefit. Research management must correctly identify the most needed projects and see that they are initiated. Priority projects are those that will most increase the efficiency of forest operations. Efficiency is usually rated financially, but other factors, such as job satisfaction or environmental management, may also be considered. For example, a New Zealand forestry company is interested primarily in the development of mechanical pruning equipment as a means of improving job satisfaction and retaining trained workers; any improvement in job efficiency will be a bonus.

2. Likelihood of success. The number of man-hours devoted to research is usually limited by the immediate financial needs of forest management. Therefore, researchers should be directed to projects with a high likelihood of success. Projects to be avoided are those that would involve extensive expertise unavailable within the team, those offering only marginal gains, and those that might take many years of trial and error. With hindsight FRI should not have taken on the development of an intermittent tree planter, as explained elsewhere in this paper.

3. Cost. The success of a project is rarely assured. Risks should be minimized generally by directing research toward low-cost projects. Costs should also be weighed against the expected benefits.

Collection of information

A literature search can save valuable time and effort during development. An existing machine or tool might be fully able to do the required job. In addition, equipment developers must be especially alert to the likelihood of infringing patents. At FRI, the search can be facilitated by computer links with other research centers.

Developers sometimes travel overseas to obtain needed first-hand experience with developments. One developer for example, travelled extensively to appraise aerial topdressing methods before undertaking major development work in New Zealand.

Establishment of liaison

Before design work begins, developers need to communicate with the eventual users of, and probable customers for, the new machine or tool; their managers; and any construction contractors likely to be involved in the development. Workers who are doing manually a job for which equipment is to be developed have an intimate knowledge of what is involved; developers cannot afford to ignore their suggestions.

Evaluation

Work study and economic analyses play major roles in New Zealand machinery design. New Zealand is a small country with abundant labor in many areas. Many development proposals are abandoned in favor of current methods once alternatives have been costed out. For example, the FRI considered developing a machine that would simultaneously cultivate and fertilize soil, but a careful evaluation of the alternatives showed that the combined operation would have been less efficient than originally thought because:

1. The operator would have had to stop cultivating periodically in order to replenish the supply of fertilizer.

2. Fertilization with the cultivation machine would have been slower than with aerial application, and expensive fertilizer loading equipment would have been used less efficiently.

3. Portions of most areas requiring fertilizer were not workable by tractor; such areas would have been more efficiently fertilized aerially or by hand.

Funding of development

Money is essential for equipment development. If some of the costs are borne by the eventual users of a development, whether forest owner or the government, the users are likely to take a continuing interest in bringing the project to a successful conclusion. Unless the financial controller is involved directly, development can become ponderously slow with the interposition of bureaucracy between those authorizing the funds and those doing the research.

Design and Construction

Silvicultural equipment has to involve more than just engineers. Silvicultural and work study specialists provide essential guidelines within which the engineer must work. In one instance, a local engineer heard of FRI's interest in developing mechanical pruning equipment, and reckoned he could build a machine to do the job in "no time flat". Only when researchers described the arrangement of branches, pruning standards, and the speed of manual methods did he understand the difficulties.

Similarly, other members of the team must learn to understand the constraints on development imposed by engineering considerations.

Extension/marketing

Developers need a system that ensures recovery of as much of the development cost as possible through marketing. The system should involve people with a thorough knowledge of patent law and experience in manufacturing and marketing.

Training of users may also be important. The team may be required to write manuals or design training courses.

THE ORGANIZATION

Control

At the FRI, silvicultural equipment development is guided by a committee (SEDC) of five members, one from the Institute, one from New Zealand Forest Service (NZFS) management, two from the New Zealand Forest Owners Association (NZFOA), and one independent member who serves as

Chairman. The members have a wide range of backgrounds and a wealth of experience. Thus, the committee is well equipped to initiate and control development.

The SEDC administers a trust account containing dollar-for-dollar contributions from the NZFOA and the NZFS. From 1972 to 1974, the committee reported directly to the Director General of Forests. Subsequently, it was reconstituted as an independent body controlling its own development funds, an arrangement that has proved vital to the success of the venture.

Committee meetings are held every few months to review progress and proposals for new projects. Researchers are invited to the meetings on an **ex officio** basis to present updates of their work. Although it is largely researchers who initiate development, the SEDC sets priorities for projects on the basis of questionnaires sent to members of the NZFOA and staff of the NZFS.

Development

Researchers and developers are teamed in the multi-disciplinary SERG. The team embodies expertise in silviculture, engineering, work study, and management. Currently, SERG consists of:

1. three technical officers, one of whom leads the team. (All have extensive field management experience).

2. two scientists, each of whom has a B.Sc. in forestry and some field management experience. (They are also knowledgeable in statistics and computer science).

3. one mechanical engineer, who combines sound theory with practical ability to build machines

4. one forest ranger, who provides expertise in work study, as well as experience in field management

5. one technician, who helps team members in all aspects of the development.

The NZFS pays the salaries of team members and provides office and workshop facilities. Not all work undertaken by SERG team members is under the auspices of SEDC; some is paid for wholly by the NZFS. The workload of each member is reviewed annually under normal FRI procedures. Conflicting priorities are rare.

The development team keeps abreast of new developments, field requirements, and the performance of new equipment through its many contacts in the forest industry. Without this interaction, the group could not function effectively. Team members are frequently called on to lecture to field workers, managers, and forest ranger trainees.

From time to time, engineering work is contracted out but remains under the team's supervision. For example, an experimental cultivation rig, a job too large for our workshop, was built to our specifications by a local manufacturer. In another instance, the team arranged for an electronic engineer, who specialized in radar navigational equipment for helicopters, to build

circuitry for an instrument to display true ground speed to the pilot. The circuitry was integrated with software developed at FRI to control a hopper gate and hence the flow rate of aerially applied fertilizer.

Located on the FRI campus at Rotorua, SERG benefits from the Institute's library, vehicle pool, typists, draftsmen, computing facilities, engineering services, and other forms of support. FRI's experts, in fields ranging from tree physiology to wood technology, are readily accessible for advice. SERG also benefits from its central location in a district that contains one of the largest man-made forests in the world.

Results are reported through the FRI publication system, although extension is probably accomplished most effectively through visits made to managers on their own forests. In addition, field days are held to demonstrate new equipment and techniques to the forest industry.

Marketing

Marketing a new machine can involve even more effort than the original development. Three avenues are open to SERG once development has been completed:

1. The project can be handed over to a venture capital firm, such as the Development Finance Corporation (DFC) of New Zealand, for licencing and manufacture. The DFC has expertise in patent law and has specific procedures for selecting manufacturers. Developers can be called on to assist with the building and testing of a manufacturer's prototype and with the writing of operational manuals.

2. Manufacturing rights can be granted to a firm directly. The government may receive a royalty on each unit sold and/or an "up front" payment, depending on the agreement negotiated. For developments that promise to improve plantation performance, royalties may be waived in order to promote the manufacture and use of the new product for the benefit of forestry in general. This has been the case with small items designed to improve care during the transport of planting stock to the field. It is important to select manufacturers carefully. Ideally, the manufacturer should be capable of producing the required number of units, enthusiastic about the development, and close enough to FRI for researchers to oversee initial construction.

3. Some developments can be made available to users through plans provided at a nominal fee. This is particularly applicable to items such as seedling transport crates, which can be made readily in any workshop and cannot practically be patented.

DISCUSSION OF PROJECTS

Seed extraction equipment

The extraction process was known to cause considerable damage to radiata pine (*Pinus radiata* D. Don) seeds. Genetically improved seed was in short supply, and such loss of this seed was unacceptable. The drum extractor was rebuilt to reduce damage. Also, dewinging and cleaning by water have been found to cause less damage than did traditional mechanical methods.

Precision seed sowers

Two seed sowers for use in forest tree nurseries have been designed at FRI. SERG was involved in the evaluation of the vacuum drum sower (Hiscock et al. 1981). This sower, marketed through the DFC and a local manufacturer, is used in most New Zealand nurseries. Several have been exported.

A vacuum disk sower is still under development. The unit was developed by a scientist who is a member of SERG, but the rights to construction of a prototype were acquired by a private company. The company has had many other priorities, and further development has been slow until recently. Construction is now well under way. Although the vacuum drum sower works very well in most forest nurseries, the disk sower is designed to handle a wider range of seed and work in rougher conditions. The two machines have been developed in parallel.

Seedling culling

SERG has developed techniques for preharvest culling of nursery stock. The most widely used system involves a frame, upon which the cullers sit, attached to the rear of a tractor. As the frame passes over a nursery bed, the cullers are able to select and cull poor seedlings with ease. The system eliminates the need for culling (and extra handling) after lifting (Trewin 1978a).

Seedling belt lifters

Using funds provided by the New Zealand Lottery Profits Board, SERG has developed a seedling belt lifter (Fig. 1) that has several advantages over earlier models. It is cheap, lightweight, can be carried on a three-point linkage, and is powered by the power take-off of a tractor. An integral part of the development is the addition of a packaging system that interfaces with the FRI outplanting system (Trewin 1976). Also, an electronic height sensor has been fitted to the harvesting head, facilitating accurate root trimming and packing. Currently, a root trimming system is being developed for use in conjunction with the lifter, since untrimmed roots are difficult to plant properly.

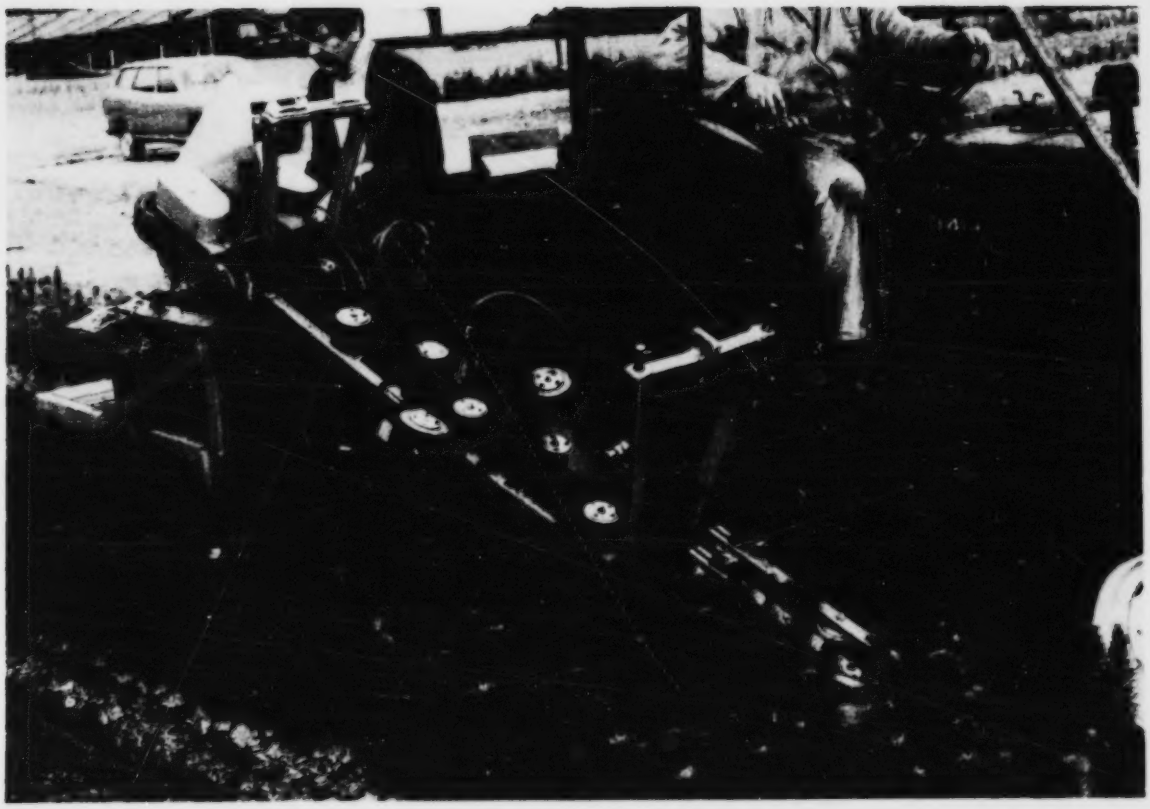

Figure 1. The FRI belt lifter in operation.

Land clearing

SERG has evaluated many land clearing techniques, including the use of V-blades (Fig. 2), shear blades, and root rakes (Page 1974, 1975b, 1975c; Ballard and Mason 1978, Anderson 1979). SEDC has not been involved because no major equipment has been developed by FRI, but the information gathered has been of great value to the industry. Stump extractors have been evaluated (Page 1975d, Everts 1981). Also, SERG was responsible for studies that led to the now widespread use of tachographs to monitor machine performance in New Zealand (Everts 1977); a tachograph records the periods a machine is in motion, and this provides a tool for both work study and management.

Figure 2. V-blades can be used to provide access and create mounds upon which the trees are planted.

Gravity rollers

Twin- and single-rope gravity rollers have been built by contractors in several parts of New Zealand (Page 1975b, Everts 1981). This equipment is used to crush scrub regrowth on steep land (Fig. 3). A twin-rope gravity roller can be steered by selective operation of the clutches on the line spools. SERG has monitored the developments and performed production studies of the various units. Though not directly involved in development, SERG has served as a repository of information.

Figure 3. Gravity rolling, a New Zealand invention.

Cultivation equipment

Over the last decade, SERG has been involved with the development of many kinds of cultivation equipment. Most of the machinery has been designed by contractors, but SERG was responsible for the now routine attachment of wings to the base of ripper tines (Page 1977), and provided advice during the construction of toolbar-mounted ripper/mounder equipment (Page 1979, Cullen and Mason 1981).

In addition, SEDC has funded the construction of an experimental cultivation rig (Fig. 4) that can perform a wide variety of cultivation treatments. The biological responses of trees to these treatments are being determined in experiments throughout New Zealand.

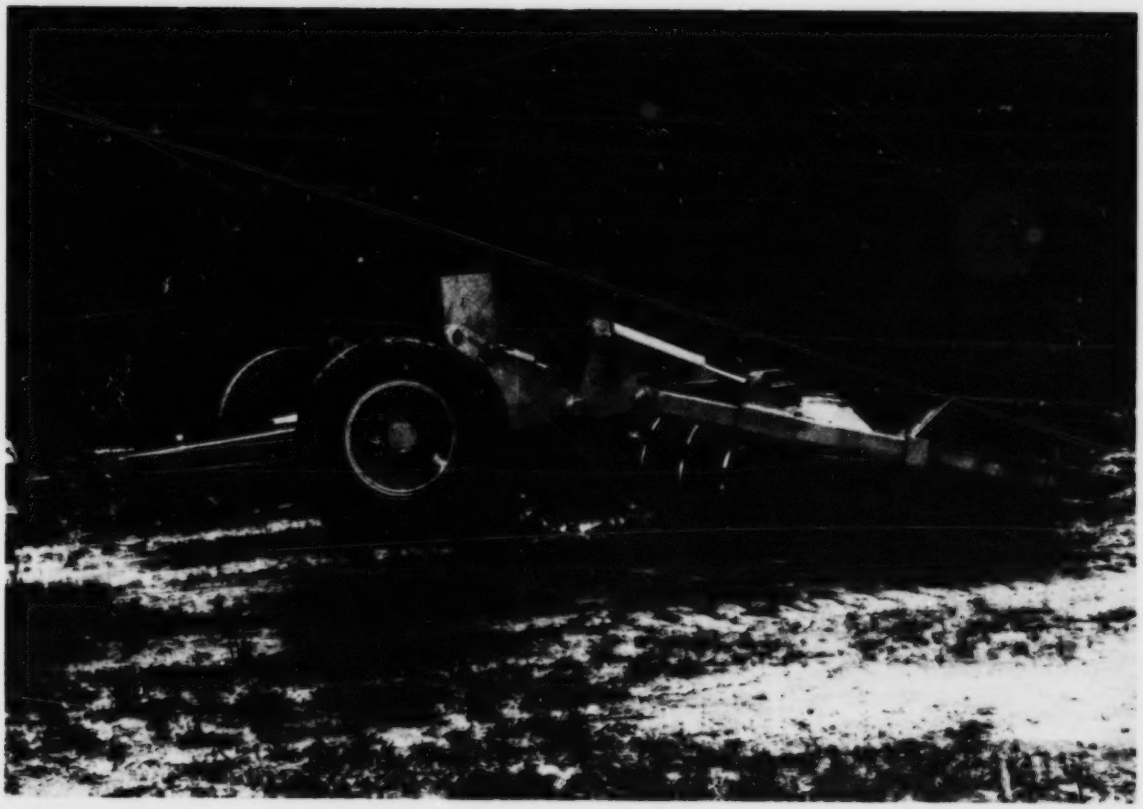

Figure 4. The FRI cultivation rig can be used for simple ripping or, with disks and rollers added in a variety of configurations, a range of cultivation treatments.

Seedling transport

SERG has developed a system for harvesting, transporting, and planting bare-root seedlings (Trewin 1978b, 1981). The system (Fig. 5) helps maintain seedlings in good condition until they are planted. SEDC has financed the construction of a trailer for transporting seedling crates, but most of the developments have been of small, inexpensive items. The system is now used in most forests in New Zealand.

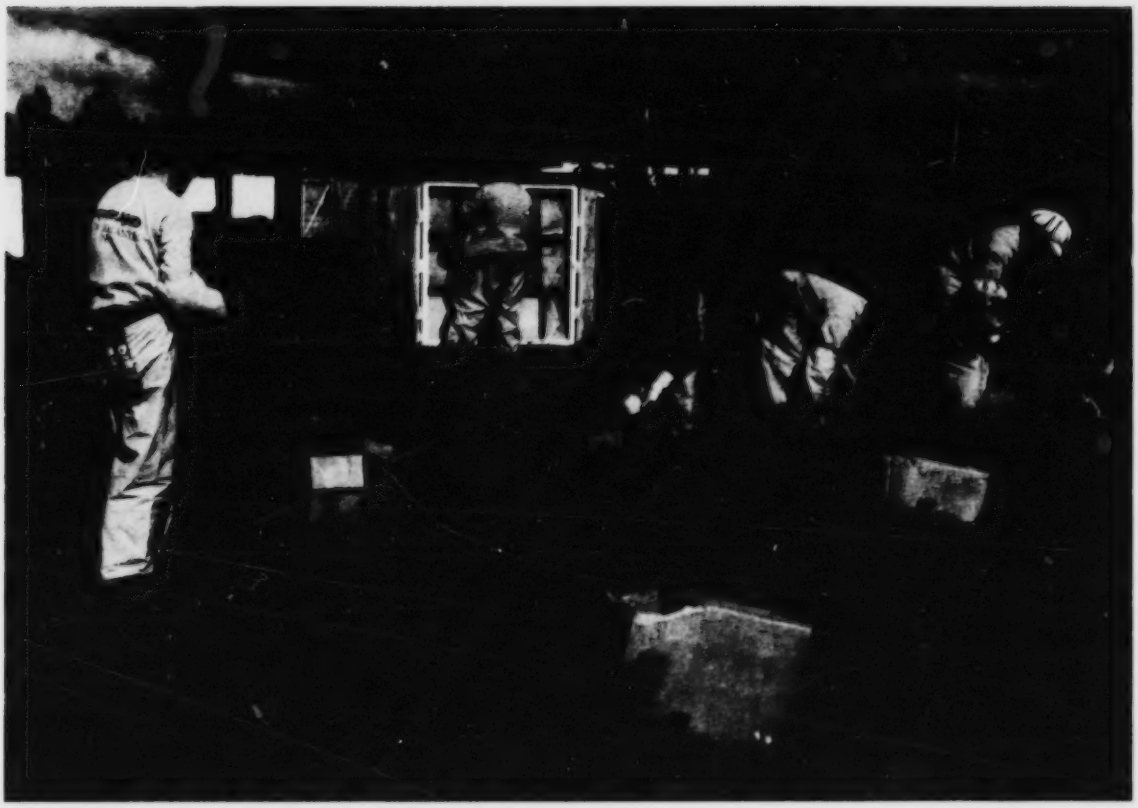

Figure 5. The FRI seedling handling system employs cardboard cartons and crates to help maintain seedlings in good condition until they are planted.

Manual tree planting

Hand planting tools and methods have been studied, and some new tools have been developed (Balneaves and Cullen 1981). Large sums of money were not required, so SEDC has not been involved in the project. In addition, the causes and effects of instability of juvenile radiata pine have been studied by SERG (Mason 1979, 1985). As a result of these studies, manual tree planting methods are under review.

Mechanized tree planting

SERG has been involved in studies of continuous furrow planters; however, as most plantations in future are likely to be established on cutover sites, much effort has been expended on developing an intermittent tree planter (ITP) (Page 1975a). After a thorough evaluation of the Quickwood ITP, SERG embarked on the construction of an ITP funded by SEDC. A working prototype was built (Coates et al. 1980) but has not progressed beyond that stage. Many of the FRI ITP's features were similar to those of the Marden ITP (one of which was subsequently imported and evaluated), but neither machine can compete favorably with manual planting in New Zealand. In retrospect, the degree of difficulty of, and the benefits to be gained from, such a development were not accurately assessed when the project was initiated. The predicted labor shortages have not materialized.

Aerial Application

FRI studies (Hedderwick and Will 1982) have shown that the use of radar navigational equipment can significantly improve the accuracy of aerial forest fertilization treatments. The SEDC has funded the building of a fertilizer hopper fitted with an electronic control that adjusts the gate opening in accordance with the radar-measured ground speed. The development continues.

Pruning equipment

SERG is currently engaged in evaluating both manual and mechanical pruning equipment (Everts 1978). Manual methods involve several different kinds of saws, shears, and ladders. The mechanical methods include devices powered by petrol (gasoline), compressed carbon dioxide, butane, and hydraulics. To date, mechanical methods barely compete with standard, extremely efficient, manual methods. SEDC has funded the private development of a pruning system powered by compressed carbon dioxide.

SUMMARY AND CONCLUSIONS

In New Zealand, the SERG at the FRI is responsible for evaluating, designing, and developing silvicultural machines. The group has expertise in engineering, forest biology, management and work study, with members working as a team. The team is guided by the SEDC, a group of state and private enterprise employees with broad experience of forestry operations.

The partnership between SEDC and SERG has successfully evaluated and developed a wide range of tools and machinery used for seed extraction, seed sowing, seedling culling, seedling lifting and transport, land clearing, cultivation, manual and mechanical tree planting, pruning, and aerial application of fertilizers.

The success of the SEDC/SERG partnership is attributable to several key factors:

1. SEDC, a body directly involved in the research, can allocate funds as needed by SERG. Committee members have the background and experience necessary to guide equipment development.

2. The researchers are organized as a multi-disciplinary team that brings together the necessary expertise.

3. The team is located within a large, supportive research establishment.

4. Close liaison is maintained with forest managers and contractors.

ACKNOWLEDGMENTS

We gratefully acknowledge the helpful criticism of this paper by Messrs. A. R. D. Trewin, P. F. Olsen, and G. Fry, and Dr. M.D. Wilcox.

LITERATURE CITED

Anderson, P.O. 1979. V-Blading: inexpensive single-pass operation. p. 11 *in* FRI looks at Mechanization No. 57. **Forest Industries Review** (April).

Balneaves, J.M. and Cullen, A.W.J. 1981. Hand planting operations. p. 246-270 *in* Forest Nursery and Establishment Practice in New Zealand, Part 2: Establishment Practice. Proc. Symposium No. 22, New Zealand Forest Services, Forest Research Institute.

Ballard, R. and Mason, E.G. 1978. Windrowing is a useful tool but... . p. 35-36 *in* FRI looks at Mechanization No. 47. **Forest Industries Review** (May).

Brown, G.W., Bentley, W.R., and Gordon, J.C. 1982. Developing harvesting systems for the future: Linking strategies, biology and design. **Forest Products Journal** 32(6):35-38.

Coates, P., Everts, D., and Cullen, J. 1980. The development of an intermittent planting machine. p. 1-4 *in* What's New in Forest Research No. 81, New Zealand Forest Services, Forest Research Institute.

Cullen, A.W.J. and Mason, E.G. 1981. The use of cultivation as an aid to forest establishment. p. 115-126 *in* Forest Nursery and Establishment Practice in New Zealand, Part 2: Establishment Practice. Proc. Symposium No. 22, New Zealand Forest Services, Forest Research Institute.

Everts, D. 1977. Tachographs for machine evaluation and management. p. 23-27 *in* FRI looks at Mechanization No. 38. **Forest Industries Review** (July).

Everts, D. 1978. The "Limb Lopper" hydraulic pruner. p. 18 *in* FRI looks at Mechanization No. 54. **Forest Industries Review** (December).

Everts, D. 1981. Gravity rollers: a land-preparation technique for steep country. p. 1-4 *in* What's New in Forest Research No. 103, New Zealand Forest Services, Forest Research Institute.

Hedderwick, G.W. and Will, G.M. 1982. Aerial topdressing of forests. p. 1-4 *in* What's New in Forest Research No. 114, New Zealand Forest Services, Forest Research Institute.

Hiscock, D., Van Dorsser, J., and Mason, E.G. 1981. Precision seed sowing becomes a reality. p. 1-4 *in* What's New in Forest Research No. 96, New Zealand Forest Services, Forest Research Institute.

Mason, E.G. 1979. They might grow well, but will they stand up? p. 8-11 *in* FRI looks at Mechanization. **Forest Industries Review** (December).

Mason, E.G. 1985. Causes of juvenile instability of radiata pine in New Zealand. **New Zealand Journal of Forest Science** 15:283-280.

Page, I. 1974. Shear blades. p. 12 *in* FRI looks at Mechanization. **Forest Industries Review** (September).

Page, I. 1975a. Early attempts at mechanizing cutover replanting. p. 22-23 *in* FRI looks at Mechanization. **Forest Industries Review** (March).

Page, I. 1975b. Gravity rolling at night. p. 14-17 *in* FRI looks at Mechanization. **Forest Industries Review** (August).

Page, I. 1975c. Land clearing machinery: determining the needs. p. 23-24 *in* FRI looks at Mechanization. **Forest Industries Review** (February).

Page, I. 1975d. Stumping with a hydraulic excavator. p. 19-20 *in* FRI looks at Mechanization. **Forest Industries Review** (November).

Page, I. 1977. Improving the efficiency of ripping. p. 28, 31-32 *in* FRI looks at Mechanization No. 39. **Forest Industries Review** (August).

Page, I. 1979. Enterprise shown in difficult northland soil. p. 13 *in* FRI looks at Mechanization No. 56. **Forest Industries Review** (March).

Trewin, A.R.D. 1976. An integrated system for the mechanical harvesting of pine seedlings. p. 2 *in* Forestry Research No. 42, New Zealand Forest Services, Forest Research Institute.

Trewin, A.R.D. 1978a. Culling methods can improve pine seedling quality. p. 23-24 *in* FRI looks at Mechanization No. 49. **Forest Industries Review** (July).

Trewin, A.R.D. 1978b. Pine seedlings: handle with care! p. 1-4 *in* What's New in Forest Research No. 67, New Zealand Forest Services, Forest Research Institute.

Trewin, A.R.D. 1981. The importance of a good outplanting system for the establishment of bare-root pine seedlings. p. 226-238 *in* Forest Nursery and Establishment Practice in New Zealand, Part 2: Establishment Practice. Proc. Symposium No. 22, New Zealand Forest Services, Forest Research Institute.

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SESSION II - EQUIPMENT/SOIL-SITE INTERACTION

SOIL COMPACTION BY LOGGING AND SITE PREPARATION EQUIPMENT: EFFECTS ON SEEDLING GROWTH ON FOUR SOIL TYPES IN WEST-CENTRAL ALBERTA, CANADA

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KEYWORDS: soil compaction, site preparation, effects of logging on soil, Alberta, coniferous regeneration, soil bulk density

INTRODUCTION

Intensified interest in site classification and land evaluation for optimizing resource expenditure and allocation has led to a desire to characterize and quantify site properties, potentials, and responses to management in managed forest ecosystems. Incidental side effects on soils from the use of heavy forestry equipment can be serious. In particular, the problem of soil compaction and its influence on tree growth has been widely recognized (cf. Lull 1959, Froehlich 1978, 1982, Greacen and Sands 1980, Froehlich and McNabb 1984). However, few quantitative data have been published on the effects of soil compaction on tree growth in the Canadian boreal forest.

This paper reports the effects of heavy (summer logging and site preparation) equipment on the bulk densities of four soil types differing widely in physical properties. The influence of soil compaction on the growth of white spruce (*Picea glauca* [Moench] Voss) and lodgepole pine (*Pinus contorta* Loudon var. *latifolia* Engelm.) seedlings in the greenhouse is also reported.

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[1] Now Forestry Canada, Northwest Region

Study area

The study area is located between 116° and 118°W and 53° and 54°N within the St. Regis (Alberta) Forest Management Agreement area in west-central Alberta, Canada. The towns of Edson and Hinton lie within the study area. The climate is humid continental, with cold winters and cool summers. Freezing temperatures can occur in any month. The mean annual temperature at Edson is 1.7°C; mean monthly temperatures are above freezing from April through October (the highest is 14.9°C in July and the lowest is -14°C in January); annual precipitation averages 55 cm, half of which falls as rain in June, July, and August (Anon. 1975). Annual potential evapotranspiration ranges from 45 to 50 cm (Anon. 1969).

Surficial geology and soils

Ice covered parts of the study area during the Cordilleran and Keewatin glacial periods. The Cordilleran ice affected terrain that includes about two-thirds of the study area in the south and west (Roed 1968). The rest of the study area was covered by Keewatin ice in at least two ice advances. Surficial deposits include Keewatin and Cordilleran ground moraines, Tertiary glaciolacustrine silts, clays with bedding, coarse glaciofluvial gravels forming terraces and benchlands, aeolian sands, and recent alluvial deposits. Small outcrops of shale, sandstone, coal, and conglomerate occur in the more mountainous southwestern areas.

Soils of the Luvisolic, Brunisolic, Gleysolic, Regosolic, Podzolic, and Organic orders of the Canadian Soil Classification System (Can. Soil Survey Comm. 1978) are present in the Edson area. The dominant soil subgroups ranked in order of decreasing abundance are Brunisolic Gray Luvisols, Mesisols, Orthic Gray Luvisols, and Orthic Gleysols (Dumanski et al. 1972). Sample plots were located on soils of the Marlboro, Hinton, Lendrum, and Summit soil associations described by Dumanski et al. (1972).

Vegetation

The study area lies within the Lower Foothills (B19a) and Upper Foothills (B19c) Sections of the Boreal Forest Region (Rowe 1972). The forests are dominated by lodgepole pine, but black spruce (*Picea mariana* [Mill.] B.S.P), white spruce, trembling aspen (*Populus tremuloides* Michx.), balsam poplar (*P. balsamifera* L.), and alpine fir (*Abies lasiocarpa* [Hook] Nutt.) also occur.

EXPERIMENTAL METHODS

Field

Each study area was selected to provide a chronosequence of clearcutting and site preparation of at least 20 years on a predominantly single soil association (Dumanski et al. 1972). The soils of the four areas selected differed widely in physical properties, especially texture:

- Lendrum: moderately well to imperfectly drained Orthic Gray Luvisol on stone-free lacustrine silty clay

- Marlboro: moderately well to well drained Brunisolic Gray Luvisol on cobbly clay loam till overlain by silt loam fluvio-aeolian veneer

- Summit: well to rapidly drained Brunisolic Gray Luvisols and Eluviated Eutric Brunisols on sandy loam to clay loam cobbly Tertiary glacio-fluvial deposits

- Hinton: well to imperfectly drained Cumulic Regosols on aeolian silt loam to loam.

These soils encompass most of the variability encountered in soil physical properties in the Edson area.

Summer-clearcut stands of three or four age classes (depending on the availability of current-year clearcuts) were selected on each soil type, and three sample plots were established in each age class. Control plots were established, two each on the Lendrum and Marlboro soils, one each on the Hinton and Summit soils.

In each sampled stand, a 50-m baseline was run through the cleared block on a compass bearing that avoided obvious trails, landings, wet depressions, standing trees, and steep topography. Soil moisture and bulk density determinations were made at 5-m intervals along the line at 1- to 10-m randomly assigned distances from the line, for a total of 10 measurements on each transect within a 0.1-ha area. At each measurement point, moisture and density counts were taken at the surface and at depths of 10, 20, and 30 cm with a Troxler model 3401B density/moisture gauge with 30.5-cm probe. The ground surface was prepared for the gauge by removing the organic layer from a 20 x 35 cm area and driving a transmission hole for the gauge probe with a Campbell Pacific Nuclear slide hammer. The thickness of the organic layer was recorded. The moisture and density counts were converted to the corresponding percent moisture and bulk density (g/cm^3) estimates with the aid of tables and algorithms provided with the gauge. The means, standard deviations, and standard errors of the mean, for moisture content and bulk density, were calculated for each depth and age class ($n = 30$) on each soil type. The results were graphed.

In the second (1985) field season, soil bulk density was determined gravimetrically from soil cores and bulk density estimates were made once more with the Troxler moisture/density gauge. Direct and indirect estimates of soil bulk density were examined by regression analysis. Regressions of bulk density determined directly from soil cores on bulk density estimated from nuclear gauge determinations were used to calibrate the gauge for each soil type[2]. Such calibration was recommended by Steele et al. (1983), who found that the relationship between nuclear gauge and gravimetric determinations varied with soil type and condition. At a representative location near each plot center, a soil pit was excavated and a soil profile was described. In one control plot per soil type, soil samples were taken from each horizon for laboratory analysis.

Greenhouse

To evaluate the effect of soil compaction on seedling growth, lodgepole pine and white spruce seedlings were grown in each of the four soils compacted to bulk densities representative of

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[2] For further discussion of this method, see Corns, I.G.W., Can. J. For. Res. 18:75-84. 1988.

various field conditions. Mineral soil from the top 20 cm of undisturbed soil profiles in uncut mature stands was air dried on greenhouse benches, and clod size was reduced gently to a diameter of 2 cm or less. The moisture content of the air-dried soil was estimated on the basis of oven-dried subsamples, and the weight of oven-dried soil of each soil association necessary to obtain predetermined bulk densities in cylindrical pots 15 cm in diameter and 20 cm high was calculated. A plastic cap on the pot base, drilled with holes and lined with filter paper, retained the soil and provided drainage. The pots were filled within 2.5 cm of the top with soil compressed incrementally by means of a Carver laboratory press (11,000 kg capacity) equipped with a piston 15 cm in diameter. The three bulk densities used (Table 1) approximate those found in the following field conditions: 1) clearcut block roads immediately after logging and site preparation; 2) clearcut block roads 5-10 years later; and 3) undisturbed control. Ten replicates were prepared for each bulk density treatment per soil. Seeds of lodgepole pine or white spruce were sown on the surface of each pot and covered with grit to prevent splashing. The pots were placed on polyethylene-lined benches under high pressure sodium vapor lighting for 18 h/day at 20°C and were watered from below. Fungicide was applied to the soil surface. Fertilizer was applied weekly in the irrigation water at concentrations of 125, 60, 159, and 5.5 ppm for N, P, K, and Fe, respectively. Seedlings were thinned to five per pot at 4 weeks and to three at eight weeks. The latter were healthy and well spaced. At 15 weeks the lodgepole pine seedlings were removed and washed free of soil over a 5-mm mesh screen to prevent loss of roots and foliage. At 24 weeks, the white spruce seedlings were similarly treated. Root depth, total oven-dried biomass per pot, and seedling top height and stem diameter were measured. Root systems of individual seedlings were not measured separately because of the difficulty of separating them.

Table 1. Soil bulk density levels used in growing lodgepole pine and white spruce seedlings in greenhouse culture.

	Bulk density (g/cm^3)		
Soil	Group 1	Group 2	Group 3
Lendrum	1.2	1.35	1.5
Marlboro	1.3	1.4	1.5
Summit	1.3	1.4	1.5
Hinton	0.7	0.8	0.9

One-way analysis of variance was used to evaluate differences in seedling growth among bulk densities within each soil type. A two-tailed t-test was undertaken to detect differences significant at P 0.05.

RESULTS

Field bulk density

Soil bulk densities on clearcuts of various ages on three of the four soil types examined in the Edson map area tend to be greatest on the most recent clearcuts and least on the oldest clearcuts (Fig. 1). Contributing to this trend is the increasing size and weight of harvesting equipment used since harvesting began in the study area in the late 1950s. The effect is evident to at least 30 cm, the greatest depth sampled. In all cases, bulk densities recorded under the mature forest were slightly greater than those on the oldest clearcuts, perhaps because of pressure exerted on the soil by root growth and tree weight (Greacen and Sands 1980). Bulk densities tended to increase with soil depth. They were greatest (0.8 to 1.65 g/cm^3) on the Marlboro soil (Fig. 1a), least on the Hinton soil (0.5 to 0.8 g/cm^3) (Fig. 1d), and intermediate on the Lendrum (Fig. 1b) and Summit (Fig. 1c) soils.

On all soils except the Hinton association, the range in bulk density between the surface and 30-cm depth was narrower on the most recent clearcuts than on the uncut controls (Table 2). Increases in bulk density with depth are greater near the surface than farther down (Table 3). Marlboro soils show the greatest increases in bulk density with depth (28 to 48% under a recent trail) in comparison with the uncut control; Summit soils showed no differences, and Lendrum and Hinton soils were intermediate. The bulk density of the Lendrum soil would probably have shown a higher maximum had a more recent block road been available for sampling; the road sampled was 19 years old. Recovery from compaction to preharvest bulk densities is estimated to require 20-21 years for the Marlboro soil, 13-15 years for Lendrum, and < 6 years for Hinton. The Summit soil was unaffected. The assumption underlying these estimates is that recovery is linear over time. On the Lendrum soil, the 19-year-old block road yielded the highest bulk densities (< 1.48 g/cm^3); this illustrates the prolonged persistence of severe compaction on this soil.

Seedling Growth

Differences in seedling growth among the three bulk density levels on the four soils were generally greater in lodgepole pine than in white spruce (Table 4), even though the spruce seedlings were 9 weeks older than the pine. The differences were most evident on the Lendrum (lacustrine) and Summit (glaciofluvial) soils. Growth was poor and mortality high on the Marlboro soil. Seedling growth was also poor on the highly calcareous Hinton soil.

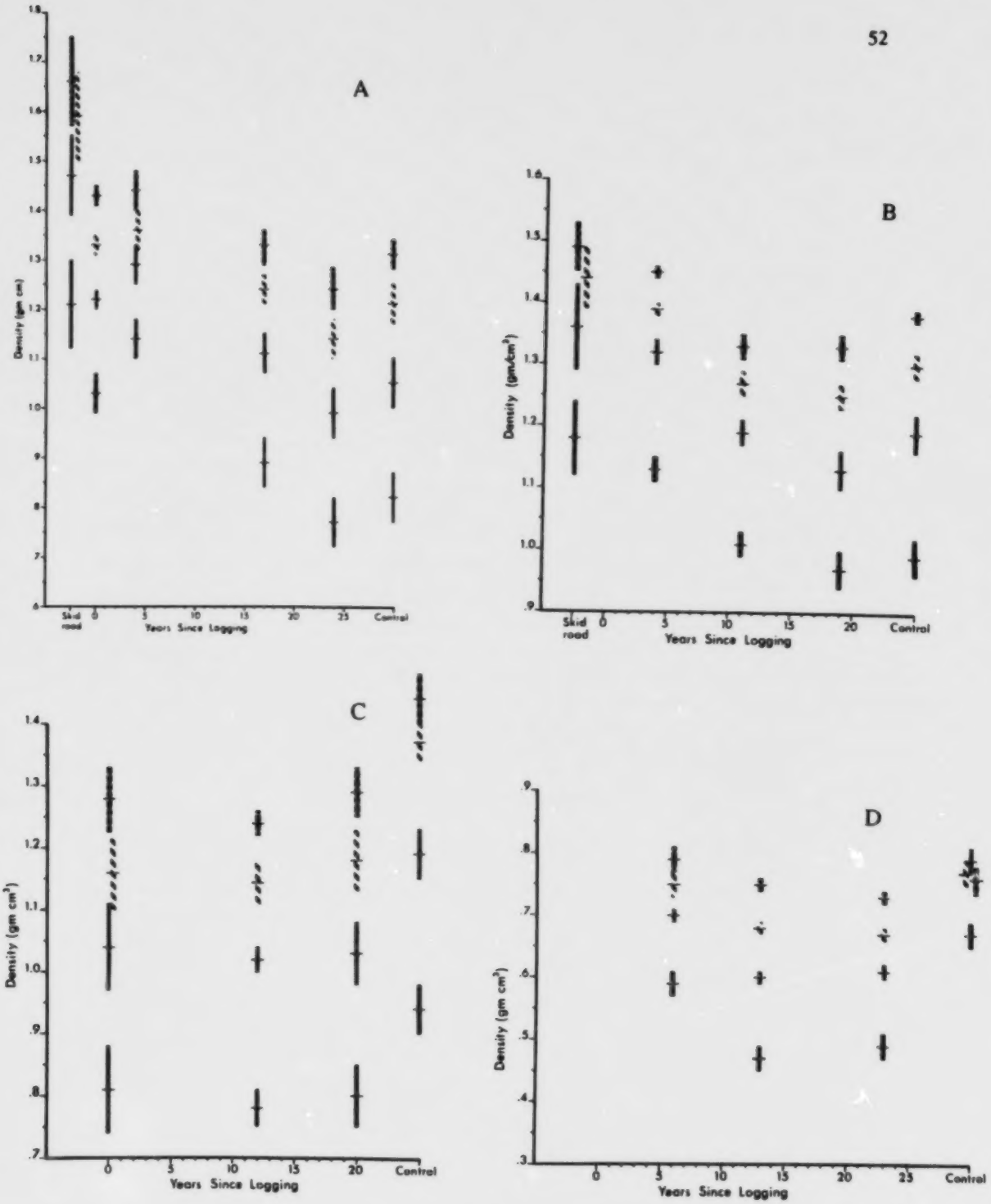

Figure 1. Mean and standard error of mean for soil bulk densities on clearcuts and uncut controls on four soil associations in west-central Alberta: (a) Marlboro, (b) Lendrum, (c) Summit, and (d) Hinton. Surface and 10-, 20-, and 30-cm depths sampled.

Table 2. Soil bulk density (g/cm^3) at the surface and the 30-cm depth on the most recent clearcuts and uncut controls.

	Most recent clearcut			Uncut forest control		
Soil	Surface	30 cm	Range	Surface	30 cm	Range
Lendrum	1.13	1.45	0.32	0.95	1.38	0.43
Marlboro	1.09	1.50	0.41	0.82	1.30	0.48
Summit	0.81	1.28	0.47	0.94	1.44	0.54
Hinton	0.59	0.79	0.20	0.65	0.75	0.10

Table 3. Soil bulk densities immediately after summer logging and an estimate of the time (years) required for them to recover from the compaction experienced during logging.

Depth (cm)	BDC[a]	BDM[b]	Increase[c]	Recovery[d]	BDC	BDM	Increase	Recovery
		Lendrum				Marlboro		
0	0.95	1.18	24	14	0.82	1.21	48	21
10	1.19	1.36	14	15	1.05	1.47	4	21
20	1.30	1.44	11	14	1.21	1.59	31	20
30	1.38	1.48	7	13	1.30	1.66	28	20
		Hinton				Summit		
0	0.65			<6	0.94	0.81	0	0
10	0.79			<6	1.19	1.04	0	0
20	0.77			<6	1.37	1.16	0	0
30	0.75	0.79	5	14	1.44	1.28	0	0

[a] Mean bulk density, uncut control.

[b] Mean maximum bulk density recorded either on recent block road or on recent clearcut.

[c] Percentage increase in bulk density from control to mean maximum recorded.

[d] Recovery time (years since logging) to revert to control (presumed original) bulk density, if linear reversion is assumed; the recovery time corresponds to the intercept opposite control bulk density at a given depth when a line is drawn between mean maximum and mean minimum bulk densities recorded at the same depth.

Table 4. Results of analyses of variance (AV) and t-tests (t) between group means for lodgepole pine (LP) and white spruce (WS) growth measurements on four soils of three bulk densities.

Soil	Species	Maximum root depth		Maximum root depth within soil		Total weight		Stem weight		Root weight		Stem diameter		Stem height	
		AV[a]	t[b]	AV	t	AV	t	AV	t	AV	t	AV	t	AV	t
Lendrum	LP	**	1–3	**	1–3	**	1–3	**	1–3	**	1–3	**	1–3	**	1–3
			2–3		2–3		2–3		2–3		2–3		2–3		2–3
	WS	**	1–3	**	1–3	**	1–3	**	1–3	**	1–3	**	1–3	**	1–3
			2–3		2–3		2–3		2–3		2–3		2–3		2–3
Marlboro	LP	**	2–3	**	1–3	NS		*		NS		*		**	1–3
					2–3										
	WS	NS		NS		*		NS		**		NS		*	
Summit	LP	NS		**	1–3	**	1–2	**	1–2	**	1–2	**	1–2	**	1–2
							1–3		1–3		1–3		1–3		1–3
	WS	NS		NS		NS		NS		NS		NS		NS	
Hinton	LP	**	1–3	**	1–3			**	1–3	**		NS		**	1–2
	WS	**	1–2	**	1–2	**	1–3	*		NS		NS		**	1–2
			1–3		1–3										

[a] NS = not significant at P 0.05; * and ** = significant at P 0.05 and 0.01 levels, respectively.

[b] t-test between group means; e.g., 1–3 indicates significance (P 0.05) of difference between means of groups 1 and 3. See Table 1 for group mean bulk density values.

For the Lendrum soil, t-tests showed that the mean growth differences tended to be significant between bulk density groups 1 and 3 and groups 2 and 3 (Tables 1 and 4).

This implies that in neither species is seedling growth impaired significantly until bulk density exceeds 1.35 g/cm^3, the bulk density for group 2. Bulk densities > 1.35 g/cm^3 occurred at the 10-cm depth in soil that had been compacted 4, but not 11, years earlier (Fig. 3). In soils compacted 11 years earlier, bulk densities > 1.35 g/cm^3 occurred at the 30-cm depth.

On the Marlboro soil, a similar trend is less evident because of unaccountable and extensive seedling mortality. However, differences in maximum rooting depth between groups 2 and 3, as determined by t-test, were significant (P 0.01), as were differences between groups 1 and 3 and groups 2 and 3 for maximum root depth inside the soil core, and between groups 1 and 3 for stem height (Table 4). This suggests that lodgepole pine seedling growth on Marlboro soil may not be impaired until bulk density exceeds 1.4 g/cm^3. Such densities at the 10-cm depth were recorded only on recent block roads (Fig. 1). The thick (often > 20 cm) organic layer on many Marlboro sites has likely helped to reduce compaction.

On the Summit soil, most measures of lodgepole pine seedling growth differed significantly among the three bulk density treatments (Table 4). This indicates that bulk densities > 1.3 g/cm^3 depress the growth of pine seedlings on the Summit soil. Such densities in the field were encountered only at the 20-cm depth in the control and at the 30-cm depth on a recent clearcut (Fig. 4). There were no significant growth differences among the white spruce seedlings on the Summit soil.

On the Hinton soil, mean growth differences in the lodgepole pine seedling group were, with the exception of stem diameter, highly significantly different between 0.7 g/cm^3 and 0.9 g/cm^3 (Table 4). Several measures of white spruce growth on the Hinton soil differed significantly among bulk densities (Table 3); root weight and stem diameter did not differ significantly between group means.

DISCUSSION

Soil compaction

It is apparent from Figure 1 that the soils under investigation in the west-central Alberta study area, with the apparent exception of the Summit soil association, have been compacted during logging and subsequent site preparation operations. The effect of forestry machinery on the physical properties of soil, especially bulk density, and on subsequent tree growth have been well documented. Lull (1959), Greacen and Sands (1980), and Froehlich (1973) have drawn attention to this widespread problem.

Compaction increases soil strength and reduces total porosity at the expense of large voids. Tree growth is reduced because of reduced water supply, restricted root space, and poor aeration (Taylor et al. 1966; Froehlich 1978, 1982; Greacen and Sands 1980; Froehlich and McNabb 1984). The trend evident for the Lendrum, Marlboro, and Hinton soil associations is for compaction (i.e., increased bulk densities) to be greater on the more recent cutovers and least on the oldest cutovers. This suggests that damage by compaction diminishes with the passage of time, likely as a result of dry/wet and freeze/thaw cycles, which depend heavily on soil texture (Greacen and Sands 1980). In the present study, estimates of recovery times for soils range from 20-21 years on the clay loam Marlboro soil (Table 3) to zero (i.e., no compaction) on the coarse-textured Summit soil. These findings agree with those of Hatchell et al. (1970) and Hatchell and Ralston (1971), who observed no recovery in a loblolly pine forest one year after compaction, but slow recovery on soils that had been logged 19 years earlier. These workers estimated that soil compacted in areas used for log decks would need 18 years to recover. Perry (1964) estimated that 40 years would be required for full recovery of infiltration capacity on an old forest road with 40% clay soil. Froehlich (1979) observed in Oregon that soil compaction from logging equipment remained readily detectable in a sandy clay loam 16 years after cutting, with bulk densities 9-18% higher than in undisturbed soils. Greacen and Sands (1980) have observed compaction of sandy soil on logging trails under radiata pine (*Pinus radiata* D. Don) 50 years after the trails were last used.

Dickerson (1976) reported that bulk density increases averaged 20%, to 1.55 g/cm³, on wheel-rutted loamy sand to silty clay loam in northern Mississippi. In the present study, the 28-48% increases in bulk density of the Marlboro soil on the logging trail are higher than those reported elsewhere.

Effects on tree growth

Especially in field experiments, the myriad factors responsible for tree growth compromise attempts to attribute growth reductions to any one factor such as soil compaction. The environmental control possible in greenhouse experiments allows the investigator to monitor some effects of treatment more closely, e.g., the effect of soil bulk densities on seedling growth. However, some questions remain as to the applicability of the results to field situations.

In the present greenhouse experiment, the range of bulk density treatments, simulating soil bulk densities from those found immediately after logging to those found under undisturbed forest, gave significant seedling growth differences for most growth attributes measured for the four soil types (Table 4). The most significant differences in growth occurred at the highest bulk density levels on the Lendrum and Marlboro soils. Such densities in the field are restricted to recent block roads and at the 20- to 30-cm depth on the clearcuts. This suggests that the direct effects of compaction on tree growth may not become evident until the roots exploit soil at the 20- to 30-cm depth. The soil bulk densities at 30 cm in the Lendrum and Marlboro controls (Fig. 1a, 1b) approach the 1.5 g/cm³ density that showed significant ($P < 0.01$) growth reduction in the greenhouse (Table 4) and may in part account for the observed paucity of root penetration below 30 cm in undisturbed conditions.

It is apparent that summer logging by power saw and rubber-tired skidder, followed by some kind of mechanized site preparation, can increase soil bulk densities in the rooting zone. The effects of compaction on root growth appear to result from a complex interaction among soil strength, water and nutrient availability, and aeration. A root must overcome the strength of the soil to penetrate a pore smaller than the diameter of the root. Because compaction both increases soil strength and decreases the number of macropores, the rate of root elongation, and therefore root length, is reduced (Greacen and Sands 1980). In a greenhouse experiment, Minore et al. (1969) grew seedlings of several Pacific coast tree species in soil compacted to three bulk density levels. They found that roots of lodgepole pine, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and red alder (*Alnus rubra* Bong.) can penetrate soil, the bulk density of which inhibited root growth of Sitka spruce (*Picea sitchensis* [Bong.] Carr.), western red cedar (*Thuja plicata* Donn), and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.). The ability of lodgepole pine to survive on heavily compacted soils is noteworthy and may account for the fact that a soil compaction problem has not been apparent in the predominantly lodgepole pine forest of the Hinton-Edson area. It seems likely, however, that bulk density levels exceeding those that limit seedling growth in the greenhouse (where moisture, nutrient, and temperature regimes are favorable) will also limit tree growth in the field (where growing conditions are usually less favorable).

Prevention and amelioration of compaction

Measures to prevent or ameliorate soil compaction are unlikely to be taken by the forest manager unless he is convinced that they are economically justified. Unfortunately, long-term data on the effects of soil compaction on tree growth in the field are scarce. Froehlich (1982) attributed to tractor logging a reduction of 48% in volume yield in a 17-year-old ponderosa pine (*Pinus ponderosa* Laws.) plantation in the Pacific Northwest of the United States. Ameliorative methods such as ripping or deep tillage are expensive; over large areas, economic justification may be difficult, but, in conjunction with site preparation, such treatment may be cost-effective locally on heavily compacted areas, such as trails and landings. The Craig-Simpson ripper plow is an example of a tool used locally for the dual purpose of loosening the soil and exposing a mineral-soil microsite for seeding or planting. Broader application of such tools to areas of soils known to be susceptible to damage by compaction should be considered.

Preventive measures are preferable to, and usually less costly than, the cures and may have other benefits. Greacen and Sands (1980) have outlined some of these. The maintenance of organic matter (as a source of nutrients and for exchange capacity, water retention, and resistance to compaction) can be achieved, in part, by avoiding severe slash burns, windrowing, and severe scarification. The encouragement of soil fauna, including earthworms in soils that support them, is desirable and can be accomplished, in part, by incorporating organic matter into mineral soil at depth. As a separate operation, this would probably be too expensive, but it could be combined with site preparation. Deep-rooted legumes, after introduction by seeding, can ameliorate compaction, fix nitrogen, and incorporate organic matter at depth (Greacen and Sands 1980).

Traffic control can also be important in minimizing compaction and erosion. This can be accomplished by using vehicles with low ground pressure (Lull 1959, Froehlich 1978) and trails designed to minimize the area of disturbance (Rothwell 1978, Greacen and Sands 1980). Wetness increases the susceptibility of soils to compaction, and highly compactable soils should be avoided during spring thaw and after heavy rains. The most susceptible soils should be logged in winter when the soil is frozen. Soil surveys, available for much of the commercial forest land in Canada, should be used for identifying areas of wet and easily compactable soils.

SUMMARY AND CONCLUSIONS

A 19- to 24-year chronosequence of logging and subsequent mechanized site preparation was examined on four west-central Alberta soil types differing widely in texture for the purpose of evaluating residual effects of heavy equipment on soil bulk density. Compaction, evident on three soils, was greatest on soils of the Marlboro association. It was estimated that Marlboro soil bulk densities would need 20-21 years to recover to their preharvest levels. Soils of the Summit association were free of compaction.

Lodgepole pine and white spruce seedlings were grown on the four soils compacted in the laboratory to three bulk densities approximating the range of those occurring in the field. Significant differences in seven measures of seedling growth were observed among treatments.

Damage to forest soil through compaction by heavy equipment, though often hidden, has been found to reduce forest productivity in many parts of the world. On the basis of field determinations of soil bulk density and greenhouse determinations of growth responses of seedlings of local tree species to field-simulating levels of bulk density, losses of productivity in the Canadian boreal forest are probably similar in magnitude to those recorded elsewhere. In some soils in the boreal forests of Alberta, compaction appears to persist for several decades in spite of annual freeze-thaw cycles.

Recognition by forest resource managers of the potential for productivity losses after vehicular compaction of soil should lead to logging designs and schedules for minimizing the adverse impact of heavy equipment. Soil surveys, available for many forest leases, should be used for this purpose.

LITERATURE CITED

Anon. 1969. Atlas of Alberta. University of Alberta Press, Edmonton, and University of Toronto Press, Toronto. 157 p.

Anon. 1975. Temperature and precipitation normals 1941-1970. Department of the Environment, Atmospheric Environment Service, Downsview, Ontario 198 p. (Temperature). 333 p. (Precipitation).

Canada Soil Survey Committee 1978. The Canadian system of soil classification. Department of Agriculture, Subcommittee on Soil Classification, Publ. 1946. 164 p.

Dickerson, B.P. 1976. Soil compaction after tree-length skidding in northern Mississippi. **Soil Science Society of America Proceedings** 40:965-966.

Dumanski, J., Macyk, T.M., Veauvy, C.F., and Lindsay, J.D. 1972. Soil survey and land evaluation of the Hinton-Edson area. Alberta Soil Survey Report No. 31, 119 p.

Froehlich, H.A. 1973. The impact of even-age forest management on physical properties of soils. p. 190-220 *in* R.K. Hermann and D.P. Lavender, *Ed.* Even-age Management Symposium. Oregon State University, School of Forestry, Corvallis.

Froehlich, H.A. 1978. Soil compaction from low ground-pressure, torsion-suspension logging vehicles on three forest soils. Oregon State University, Forest Research Laboratory, Corvallis. Research Paper 36, 12 p.

Froehlich, H.A. 1979. Soil compaction from logging equipment: effects on growth of young ponderosa pine. **Journal of Soil and Water Conservation** 34:276-278.

Froehlich, H.A. 1982. The effects of mechanical operations on soil physical properties and forest productivity. Presentation to IUFRO Symposium on Site and Continuous Productivity, Seattle, Washington, 22-28 Aug. (mimeo).

Froehlich, H.A. and McNabb, D.S. 1984. Minimizing soil compaction in Pacific Northwest forest. p. 159-192 *in* E.J. Stang, *Ed.* Forest Soils and Treatment Impacts. Proceedings of 6th North American Forest Soils Conference., Knoxville, Tennessee, 1983.

Greacen, E.L. and Sands, R. 1980. Compaction of forest soils: a review. **Australian Journal of Forest Research** 18:163-189.

Hatchell, G.E., Ralston, C.W., and Foil, R.R. 1970. Soil disturbances in logging. **Journal of Forestry** 68:772-775.

Hatchell, G.E. and Ralston, C.W. 1971. Natural recovery of surface soils disturbed in logging. United States Department of Agriculture, Forestry Service, **Tree Planters' Notes** 22:5-9.

Lull, H.W. 1959. Soil compaction on forest and range lands. United States Department of Agriculture, Forestry Service, Miscellaneous Paper 768. 33 p.

Minore, D., Smith, C.E., and Wollard, R.F. 1969. Effects of high soil density on seedling root growth of seven Northwestern tree species. United States Department of Agriculture, Forestry Service, Research Note PNW-112. 6 p.

Perry, T.O. 1964. Soil compaction and loblolly pine growth. United States Department of Agriculture, Forestry Service, **Tree Planters' Notes** 67:9.

Roed, M.A. 1968. Surficial geology of the Edson-Hinton area, Alberta. Ph.D. thesis, University of Alberta, Edmonton. 200 p.

Rothwell, R.L. 1978. Watershed management guidelines for logging and road construction in Alberta. Department of Environment, Canadian Forestry Service, Edmonton, Alberta. Information Report NOR-X-208. 43 p.

Rowe, J.S. 1972. Forest regions of Canada. Department of Environment, Canadian Forestry Service, Ottawa, Ontario Publication No. 1300. 172 p.

Steele, J.G., Koger, J.L., Troase, A.C., and Sirois, D.L. 1983. Core versus nuclear gauge methods of determining soil bulk density and moisture content. United States Department of Agriculture, Forestry Service, Research Note SO-295. 6 p.

Taylor, H.M., Roberson, G.M., and Parker, J.J. 1966. Soil strength -- root penetration relations for medium to coarse-textured soil materials. **Soil Science** 102:18-22.

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SITE IRREGULARITIES AND THEIR EFFECT ON PRIME MOVER AND SILVICULTURAL EQUIPMENT OPERATION

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KEYWORDS: whole-body vibration, silvicultural site irregularities, seat suspension system, zero-G seat, active seat

INTRODUCTION

Terrain conditions have a significant effect on the efficiency and productivity of any prime-mover/equipment operation regardless of whether the operation pertains to agriculture, forestry, or construction.

Any attempt to improve efficiency and productivity must take into consideration the factors affecting overall system performance. Only then can measures be taken to improve system performance.

The objective of this paper is to consider the effect of site irregularities on the operation of prime movers and silvicultural equipment. On the basis of previous developments in the agricultural industry, suggestions are made for reducing the effect of site irregularities on the operation of silvicultural equipment.

Role of the operator

Whether an agricultural tractor or a forestry skidder is used, and regardless of the type of equipment being towed, the efficiency of the overall operation depends on the operator. Although the equipment is designed for a particular operation, the operator must make spontaneous adjust-

ments to ensure that the quality and quantity of work are satisfactory. The operator performs a variety of tasks, some of which we tend to take for granted. It is only when we attempt to automate some of these tasks that we appreciate the many sensing, decision-making, and control functions the operator performs.

Some of the more important functions performed by the operator are:

i) guidance of the prime mover to ensure appropriate spacing between successive passes

ii) adjustment of the towed equipment to maintain the desired height or depth of operation

iii) adjustment of the forward speed appropriate to the equipment and site conditions

iv) monitoring of the performance of the prime mover and equipment for abnormal operation

v) navigation of the equipment around obstacles or extremely wet sites, or around conditions that might lead to overturning.

On level, smooth, and uniform sites, the demands on the operator are minimal. Demands are much greater, however, when site irregularities, such as rocks, stumps, terrain undulations, or changing soil conditions are present. In fact, it may well be impossible for the operator to execute the main functions noted above continually and simultaneously. In such cases the operator may establish priorities, which will vary depending on the particular operation. For example, guidance of the vehicle may be given a higher priority than equipment adjustment, in which case the quality of work performed by the equipment could be less than desirable.

Site irregularities and prime-mover/ equipment operation

Site irregularities affect the operator in various ways, as illustrated by the following examples.

Any change in rolling resistance, as a result of site irregularities encountered by the drive wheels of the prime mover, tends to change the direction of the vehicle. To maintain the vehicle on a desired course, the operator must continually make steering corrections.

Most towed equipment is supported by rolling (wheels) or sliding (skis) members in contact with the terrain surface. Although the position of the working tool is adjustable in relation to the supporting members, the position and attitude of the working tool in relation to the soil surface usually dictate the effectiveness of the operation. If the supporting members frequently encounter site irregularities, the operator must adjust the equipment just as frequently to maintain the tool in the desired position in relation to the soil surface.

The agricultural field may appear much more favorable than the forest site. However, even agricultural site irregularities present real problems to the operation of prime movers and equipment. Although there are no large stones or stumps to be navigated around, minor and major terrain undulations, as well as varying soil and moisture conditions, within a given field can affect equipment operation. This can be illustrated by a pre-seeding tillage operation. The main purpose of tillage is to kill weeds and prepare a seed bed. Effective weed kill requires cultiva-

tion at a specific depth. Too shallow or too deep cultivation results in poor weed kill. In addition, cultivation below the desired depth increases energy consumption. Similar comments apply to forest site scarification.

Agricultural equipment in western Canada is of the towed type, with the tillage tool frame supported on a number of rubber-tired wheels. Tillage depth is adjusted hydraulically by moving the support wheels in relation to the frame (Fig. 1). Throughout a given field, soil and moisture conditions can vary considerably; this will result in different sinkage depths of the support wheels and, consequently, different depths of tillage.

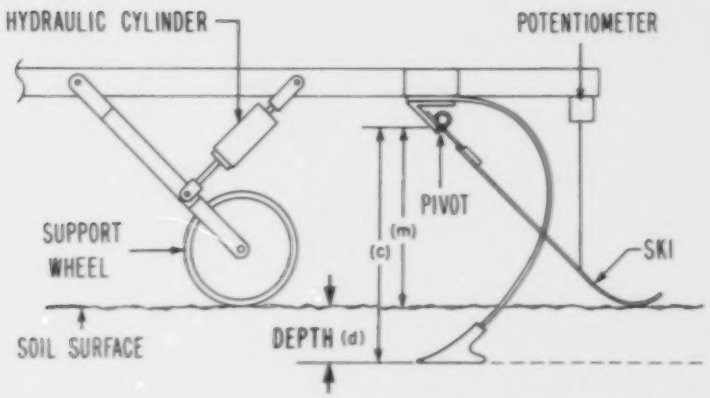

Figure 1. Typical agricultural tillage tool.

From his vantage point in the tractor cab, an experienced operator can usually assess the tillage depth required and can make the appropriate adjustments. However, in some situations, e.g., operation at night or under dusty conditions, the operator cannot accurately assess tillage depth. Consequently, in parts of the field, the treatment may be ineffective.

To overcome this problem, several forms of automatic depth control systems have been developed and marketed in recent years (Gunderson et al. 1981). Two approaches have been taken:

(i) a mechanical arm with one end pivoted on the frame and the other end attached to a ski or wheel that follows the surface of the ground. Change in the angle of the arm with respect to the frame is measured electronically and used as a signal to the control system, which automatically maintains the desired depth. (See Fig. 1)

(ii) ultrasonic sensors, mounted on the frame, to measure the distance from a point on the frame to the soil surface. Since the tip of the tillage tool is a fixed distance from the frame, the tillage depth is measured indirectly. One advantage of the ultrasonic sensors is that they are non-contact and have no mechanical linkages or members that can wear out or be damaged. (See Fig. 2)

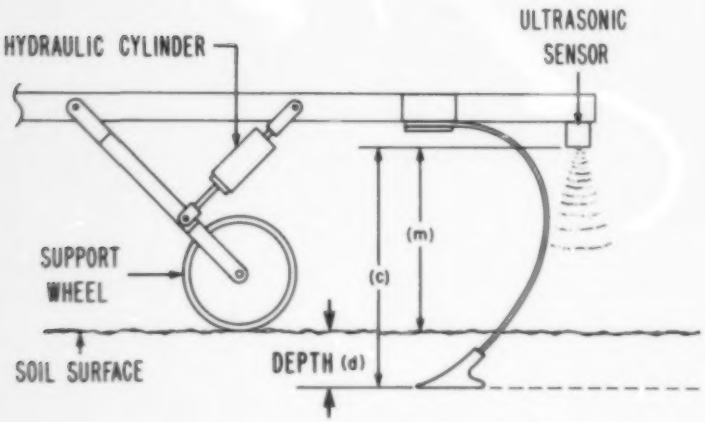

Figure 2. Ultrasonic depth measurement system

Similar or related technology could, perhaps, be employed to advantage in forest site preparation.

It should be noted that, in agricultural operations, emphasis has been placed on automating the operation of the equipment rather than on guidance of the prime mover. While guidance assists are being developed, there is great reluctance to remove the operator completely from the vehicle, partly because of the associated high cost but more because of the ability of the operator to respond better to abnormal conditions that could result in serious damage to vehicle or equipment.

Site irregularities and the operator

The conditions described above may be referred to as "macro" site irregularities in an agricultural environment, i.e., changes in field soil and moisture conditions that influence tillage depth.

Another problem that affects equipment operation indirectly and might be referred to as "micro" site irregularities, is that caused by ridges or undulations in the terrain produced during a previous pass of the equipment. These "micro" irregularities tend to excite natural frequencies associated with the spring-mass characteristics of the tractor, giving rise to whole-body vibration of the operator. The effects of whole-body vibration might have important consequences on prime mover and equipment operation.

Terrain-induced whole-body vibration has been studied by many researchers over the past 30 or more years (cf. Rosegger and Rosegger 1960, Griffin and Lewis 1978, Howat 1978, Lewis and Griffin 1978, Kam 1981). The main conclusions from that work are presented here to illustrate the possible effects of whole-body vibration on the operator and equipment operation.

The human body is a complex dynamic system and attempts have been made to model the body as a system of masses, springs, and viscous dampers (or shock absorbers). Mathews (1964) presented one such model (Fig. 3). If this "model" is placed on the seat of an agricultural tractor or a forest skidder, it could be, and usually is, subjected to a spectrum of frequencies associated with accelerations entering through the seat system. The corresponding forces must be absorbed by the buttocks, the spinal column, and the muscles of the abdominal and respiratory systems and, perhaps, other parts of the body. Measurements have shown that when a sitting individual is subjected to vertical vibration, amplitudes of the head, neck, and belt regions of the body in the 2- to 5-Hz range are as much as twice those of the buttock region (Fig. 4). Unfortunately, most terrain-induced whole-body vibration occurs in this frequency range.

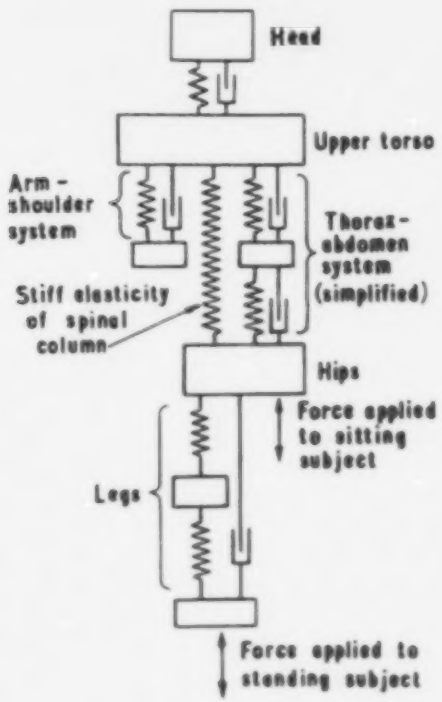

Figure 3. Model of human body (after Mathews 1964)

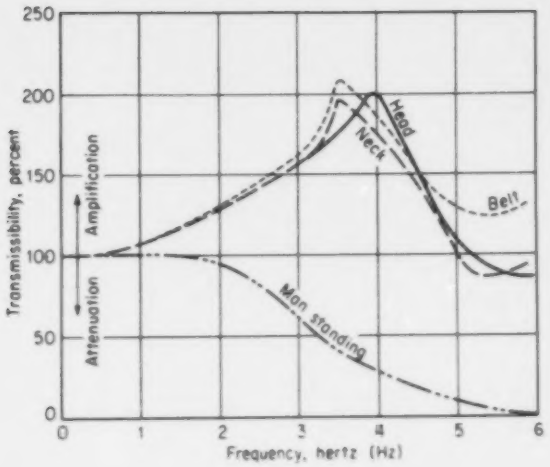

Figure 4. Mechanical response of man to vertical vibration (**after** McCormick 1976)

What are the consequences of exposure of the human body to terrain-induced whole-body vibration? The literature (cf. McCormick 1976, Lewis and Griffin 1978, Kam 1981) indicates two main effects:

i) reduced operator comfort, and a possible health risk to the operators,

ii) reduced ability of the operator to execute tasks requiring manual dexterity, and reduced visual acuity.

Both effects can have ramifications in terms of prime mover and equipment operation. As in agricultural tillage, in the absence of fully automatic control, the operator must make frequent adjustments to maintain a desired depth of tillage. Similar, and perhaps even more frequent, adjustments might be needed to maintain a desired depth of scarification, seedling placement, etc., in silvicultural operations.

If whole-body vibration impairs the ability of the operator to assess visually the performance (e.g., maintenance of desired depth) of the drawn equipment, or if the operator is unable to activate the controls as accurately as desired, there is little question that the quality of the work performed by the equipment will decline.

More significantly, the operator may incur partial disablement in consequence of prolonged exposure to whole-body vibration. This could necessitate reduction of forward speeds (to reduce acceleration amplitudes), fewer working hours per day, or even retraining for a different occupation.

How is whole-body vibration related to site irregularities? And, if we have to live with site irregularities, how can the level of whole-body vibration be reduced?

Most off-road vehicles, e.g., agricultural tractors and skidders, unlike automobiles and trucks, do not have a suspension system. With tractors, etc., only the tires separate the terrain from the vehicle frame. Except for this isolation, the motion (vertical, lateral, and longitudinal) of the vehicle frame is dictated by the motion resulting from the wheels traversing the terrain.

The operator is isolated from the frame by a seating system. This may range from a simple pad on the vehicle frame to a pad supported by a spring and shock absorber suspension system (Fig. 5). The effectiveness of the suspension system determines the degree to which the operator experiences the terrain-induced vibration in the frame.

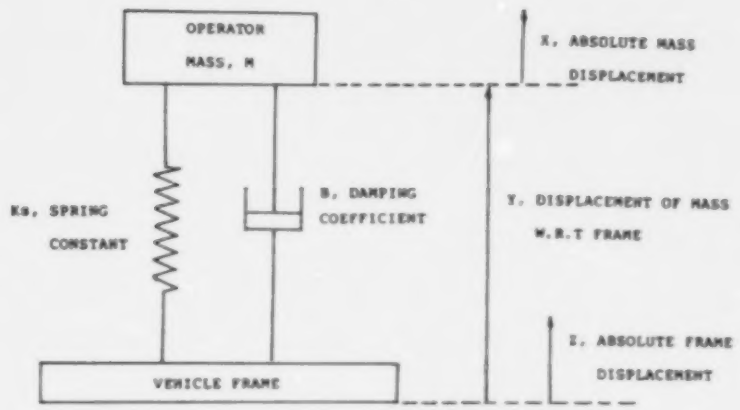

Figure 5. Schematic of passive seat suspension system

In various studies in which measurements of acceleration levels of the vehicle seat were made (e.g., Griffin 1978, Gerke and Hoag 1979), many seat suspension systems on off-road vehicles were found to be ineffective in damping whole-body vibration. Furthermore, most seat suspension systems provide isolation in the vertical direction only, none laterally or longitudinally.

One approach being developed to reduce the vertical component of vibration to the operator is that referred to as an active seat (or Zero G seat) suspension system (Grimm et al. 1975, Anon. 1979). This uses a hydraulic actuator to replace the spring-shock absorber arrangement of conventional suspension systems (Fig. 6). In addition, an accelerometer, located on the vehicle frame, measures the vertical acceleration of the frame and provides a signal to an electro-hydraulic valve which, in turn, accelerates the actuator in an **equal but opposite direction** to that of the frame. In principle, the seat, and hence the operator, should experience zero

acceleration. In practice, however, because of physical limitations of the hardware, isolation is incomplete, although laboratory and field tests (Grimm et al. 1975, Anon. 1979, Ho et al. 1984) have indicated a substantial improvement over conventional systems (Fig. 7, 8).

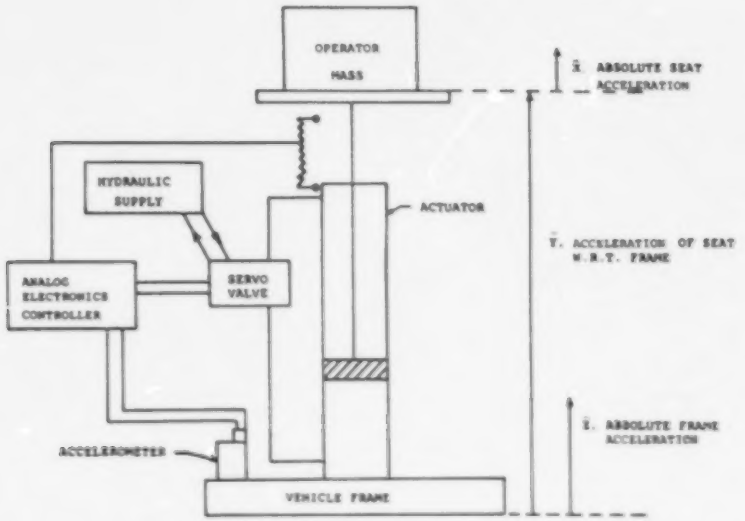

Figure 6. Active seat suspension system

Should this concept be accepted, what are the potential advantages and disadvantages in terms of site irregularities and their effect on prime mover and equipment operation?

On one hand, a more comfortable operator might be expected to be more alert and to have better control of the equipment being pulled. The operator might spend longer hours on the vehicle and thereby increase daily productivity. Productivity might also be increased by faster travel speeds, since the "bumps" would not be felt to their former degree.

On the other hand, increased forward speeds, beyond certain limits, might cause excessive stress on both the prime mover and the towed equipment. This could reduce the useful working life of both, or might increase maintenance costs and down time. Whether these additional costs would be offset by increased efficiency and productivity is an open question. Another potential problem is that of prime mover stability. Rollovers of agricultural tractors are not uncommon, and usually result from attempts to turn at too high a forward speed. Although silvicultural prime movers probably do not attain similar velocities, site irregularities together with terrain slope could very well have similar consequences. Improved isolation systems might cause the operator to lose his or her feeling for the magnitude of the irregularities encountered by the prime mover. This could lead to rollover of the prime mover. Fortunately, electronic sensors can be fitted to measure the roll position (the most likely instability), roll rate and roll acceleration. Integrated signals from these sensors could warn the operator of impending instability, or, if a more sophisticated solution were required, reduce speed automatically (by appropriate modulation of the throttle position), disengage the drive train, or completely shut down the engine. Only field experience will show the kind of protective measures required.

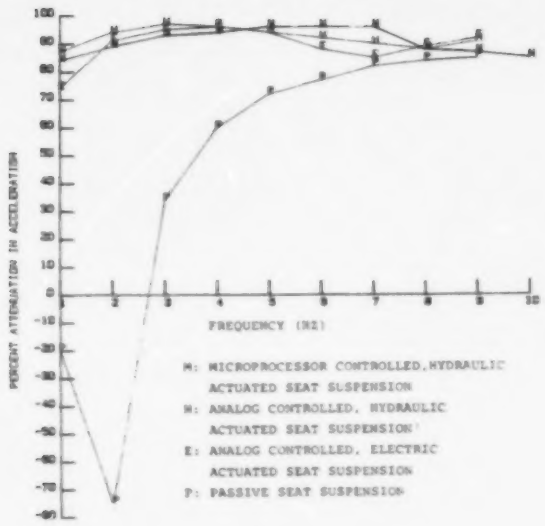
PERCENT ATTENUATION IN ACCELERATION
FREQUENCY (HZ)
M: MICROPROCESSOR CONTROLLED, HYDRAULIC ACTUATED SEAT SUSPENSION
H: ANALOG CONTROLLED, HYDRAULIC ACTUATED SEAT SUSPENSION
E: ANALOG CONTROLLED, ELECTRIC ACTUATED SEAT SUSPENSION
P: PASSIVE SEAT SUSPENSION

Figure 7. Performance comparisons of passive and active seat suspension systems (from Anon. 1979, Grimm et al. 1975, Ho et al. 1984)

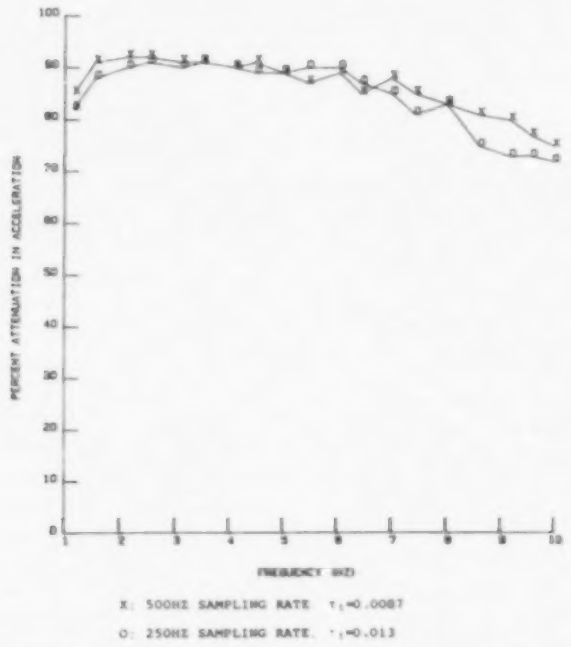

Figure 8. Laboratory performance of active seat suspension system on Komatsu D85 Bulldozer (from Ho et al. 1984)

SUMMARY AND CONCLUSIONS

This paper discusses the effects of site irregularities on prime mover and equipment in silvicultural operations. First, the effects of site irregularities are considered in relation to the functional demands placed on the operator to secure optimal performance of equipment operation. It is argued that site irregularities affect two main functions requiring operator intervention and compensation: a change in the direction or guidance course of the prime mover; and the operating depth or height of the towed equipment as a result of the support wheels traversing the irregularities.

Site irregularities also result in the operator's being subjected to terrain-induced whole-body vibration, which causes operator discomfort and, perhaps in some cases, permanent bodily damage. Either or both could result in less frequent and less accurate adjustments to the prime mover and equipment, thereby lowering the quality and reducing the efficiency of the work.

Trends developed in agricultural equipment operation indicate that the effect of site irregularities could be minimized by automating some of the operator functions and by reducing the level of whole-body vibration to which the operator is exposed.

While a completely automated prime-mover/equipment combination may be desirable, such a system is not currently considered practicable or economical.

ACKNOWLEDGMENT

The support of the Natural Science and Engineering Research Council of Canada Grant A2754, Agriculture Canada AERD File-01843-6-07625 and Canadian Forestry Service File 03ST.KN107-3-4472 is gratefully acknowledged.

LITERATURE CITED

Anon. 1979. Study of the development of a Zero-G seat suspension system for off-road vehicles; final report. University of Saskatchewan, Divison of Control Engineering, for Department of Agriculture, Engineering and Statistical Research Institute, AERD File 01843-65-07625, 35 p.

Gerke, F. G. and Hoag, D. L. 1979. Measurement of tractor vibrations at the operator's station. American Society of Agricultural Engineers, St. Joseph, Michigan, ASAE Paper 79-1078, 12 p.

Griffin, M. J. 1978. The evaluation of vehicle vibration and seats. **Applied Ergonomics** 9:15-21.

Griffin, M. J. and Lewis, C. H. 1978. A review of the effects of vibration and visual acuity and continuous manual control: Part I. visual acuity. **Journal of Sound and Vibration** 56:383-413.

Grimm, E. A., Wilson, J. N., Huff, G. J. and Ukrainetz, P. R. 1975. Further studies on an active seat suspension system for off-road vehicles. Canadian Society of Agricultural Engineering Annual Meeting, Brandon, Manitoba, June 22-26, Paper 75-308, 8 p.

Gunderson, D. G., Kirk, T. G., Wilson, J. N. and Dyck, F. B. 1981. A comparison of ultrasonic, ski and ski-wheel systems for tillage depth measurement. American Society of Agricultural Engineering, Winter Meeting, Chicago, Paper 81-1602, 11 p.

Ho, W. K., Gunderson, D. G., Burton, R. T., and Wilson, J. N. 1984. Micro-processor controlled active seat suspension system for off-road vehicles. National Conference on Fluid Power, Proceedings, Chicago, 5 p.

Howat, M. G. 1978. Exposure of front-end log load operators to whole-body vibration. Forest Engineering Research Institute of Canada, Vancouver, Technical Note TN-25, 15 p.

Kam, J. K. 1981. Effect of whole-body vertical vibration on manual dexterity test results. **American Industrial Hygiene Association Journal** 1981:556-557.

Lewis, C. H. and Griffin, M. J. 1978. A review of the effects of vibration on visual acuity and continuous manual control, Part II: Continuous manual control. **Journal of Sound and Vibration** 56:415-457.

Mathews, J. 1964. Ride Comfort for Tractor Operators, **Journal of Agricultural Engineering Research** 9:3-31.

McCormick, E. J. 1976. p. 383-389 *in* Human Factors in Engineering and Design, 4th Edition. McGraw Hill, New York.

Rosegger, R. and Rosegger, S. 1960. Health effects of tractor driving. **Journal of Agricultural Engineering Research** 5:241-244.

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PRIME MOVERS FOR SILVICULTURE: REQUIREDCHARACTERISTICS

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KEYWORDS: prime mover, site preparation, silvicultural treatment, mechanized silviculture, prime mover specifications

INTRODUCTION

Prime movers play an important role in silvicultural work. Without them many silvicultural treatments could not be undertaken. They influence strongly the cost of silvicultural operations because their capital and operating costs are usually high in relation to those of silvicultural equipment. The prime mover and its operator determine, to a large extent, the productivity of an operation. Also, in some areas there may be little choice of prime mover, and this will govern the silvicultural equipment that can be used.

The prime mover will directly or indirectly influence the overall effectiveness and efficiency of an operation through:

- the kinds of sites feasible to treat
- the percent coverage
- the treatment season
- the quality of work, (including the number of acceptable microsites produced, planting quality, and spacing between passes)
- the speed of travel between sites
- the functioning of the silvicultural implement
- the general well-being of the operator.

Consequently, the selection of prime mover is important in silvicultural work. Prime movers are an integral part of many silvicultural practices, and are especially important in site preparation, stand conversion, and stand reclamation. They are used also, though usually on a limited scale, in mechanized tree planting, seedling transport, ground applications of herbicide and fertilizer, direct seeding, and precommercial thinning.

Although few prime movers in use today were designed for silvicultural work, a great variety is potentially available from harvesting operations, road building, and agriculture.

ELEMENTS OF THE PRIME MOVER DUTY CYCLE AND REQUIRED OPERATING PROPERTIES

In silvicultural work, a prime mover must perform various functions, depending on the purpose of the treatment, the type of silvicultural equipment being used, and the characteristics of the site being treated. The duty cycle of the prime mover can be broken down into a number of basic elements, as described in the following sections. The required off-road and other operating properties are indicated with each element.

1. Continuous operation under load

In silvicultural operations, especially site preparation, the prime mover is under heavy load almost constantly. Cool-down periods are few. In contrast, a cable skidder in harvesting may work under load for no more than 40% of the time. The rest of the time is spent in light duty while the prime mover travels unloaded, delimbs and piles, or idles during loading and unloading.

Required properties: sufficient power not to overload engine; good fuel economy; adequate cooling; proper match of engine and transmission; good ergonomics in terms of noise and vibration levels and dosage, and cool cab temperature.

2. Heavy loads with high peak forces

Many silvicultural implements place a high demand for drawbar pull on a prime mover. The magnitude of this requirement is usually higher than that placed on a prime mover in its designed-for use. For example, a load of tree-length jack pine (*Pinus banksiana* Lamb.) of 4.5 m^3 (3600 kg) pulled by a 90-kW cable skidder has a mean drawbar pull (horizontal force only) of 17 kN and a peak force of 20 kN (Calvert and Garlicki 1970). The same 90-kW skidder is capable of pulling, and is often used to pull, a disk trencher. Dalström (1974) found the drawbar pull of a TTS disk trencher to have a mean force of 45-50 kN and peak force of 176 kN.

Few drawbar pull requirements (draft) have been measured for silvicultural implements (Table 1). Although information on terrain and stand conditions is limited, these data indicate a wide variation in the draft of commonly used tools and the power required at the drawbar.

Required properties: tough, rugged design in both structure and driveline; sufficient power available at the drawbar; sufficient available drawbar pull; good design and ergonomics to minimize shock forces felt by the operator.

Table 1. Drawbar pull and power requirements for various silvicultural implements.

Implement	Horizontal[a] drawbar pull requirement (kN)	Maximum horizontal force (kN)	Assumed travel speed (m/min)	Net[b] drawbar power (kW)	Source
Barrels and chains	102	na	40	68	Heikurinen (1975)
Marttiini plow KLM-240	76	na	40	51	Heikurinen (1975)
Bräcke patch scarifier	15–17	30	60	15–17	Dalström (1974)
– " –	22	na	60	22	Heikurinen (1975)
SFI patch scarifier	25–30	141	60	25–30	Dalström (1974)
Wadell scarifier	40	142	40	27	Gustafsson & Morenius (1980)
TTS disc trencher	45–50	176	60	45–50	Dalström (1974)

[a] on zero percent slope

[b] mean power output required to pull implement only, at indicated speed and on zero percent slope

3. Frequent end-of-pass turning

In a run-by-run pattern, a quick turn around to begin the next pass is needed. This becomes increasingly important as sites become smaller and as pass distances become shorter. Every other pass is at the end of the block, typically on a slope.

Required properties: tight turning circle; good lateral stability.

4. Slow, steady on-site working speed

In site preparation and mechanized planting, prime mover speed should be determined by the requirements of microsite and planting quality. In scarification operations, the speed of the prime mover may vary from 40 to 70 m/min, whereas in mechanized tree planting the speed may be as low as 20 m/min. In mechanized planting, a slow, steady pace is essential. A fast, jerky pace, and an unstable prime mover, can adversely affect planting quality. Furthermore, there is a requirement to limit the maximum distance between seedlings along the row. To allow enough cycling time for the planting mechanism, travel speed must be slow. Ground herbicide sprayers also

require a slow, steady speed and a stable prime mover to ensure even spread of herbicide over the coverage area.

Required properties: proper match between transmission type and gearing; smooth ride; ability to maintain even speed.

5. Rapid on-road travel between sites

In some areas of North America and especially in Europe, the smallness of cutovers necessitates frequent road travel between sites. The economic feasibility of an operation may depend on the ability to travel rapidly between sites. Commonly, legal restrictions on vehicles that use public roads limit the maximum width and the type of running gear (e.g., no tracks allowed).

Required properties: high road speed; legal dimensions; legal running gear or ability to change to legal running gear.

6. Complete coverage of the treatment area

Trouble spots can often be bypassed during primary transport in harvesting operations and most travel occurs on carefully routed skidroads. In road construction and agriculture, prime movers usually travel on even, prepared surfaces. In silviculture, however, complete coverage of an area, with proper spacing between passes, is frequently required; this is one of the most demanding elements of the duty cycle for a prime mover. Uphill, downhill, and sidehill travel on steep grades is necessary. Ground obstacles, such as boulders, stumps, and depressions, must be negotiated, and ground with low bearing capacity must be traversed without excessive rutting. As well, obstacles such as windfalls and residuals must be bypassed. The problem is exacerbated by the multiplicity of constraints often found within the same operating area.

Required properties: good mobility; adequate steering; high gradeability; high flotation; good lateral stability; high ground clearance; effective braking; sufficient traction; good ergonomics, primarily in terms of vibration and visibility close to the front of the machine; sufficient power and drawbar pull to overcome obstacles, grade, and rolling resistance forces, and to reach operating speed.

7. Constant stop-and-start operation

During silvicultural operations the prime mover is often brought to a stop by obstacles or difficulties in end-of-pass turning. Usually this occurs under adverse terrain conditions. The prime mover must have the ability to overcome the obstacle, then accelerate from standstill to the desired speed while under load.

Required properties: sufficient power and drawbar pull to start load moving and to accelerate; proper matching of transmission and engine; sufficient traction and/or articulated steering force to secure traction while the prime mover is hung up on an obstacle.

8. Handling of a variety of push and/or pull silvicultural equipment

Both front- and rear-operated implements are used commonly in North America. Often the same prime mover is used for both types of equipment. Examples are: (a) Eden Piling Rake and Bräcke Badger, pushed and pulled respectively, by a cable skidder; and (b) Front-mounted Cazes and Heppner Plow and Young's Teeth, and rear-mounted Craig-Simpson tooth plow or towed barrels and chains, all used with a rigid-tracked crawler tractor.

Required properties: balanced weight distribution front and rear for good stability; high flotation front and rear; good visibility both forward and aft; proper attachment points.

9. Load carrying

In some cases, the prime mover must carry a load, such as seedlings, an auxiliary engine, or a loaded reservoir.

Required properties: adequate dimensions or space; good stability with carried load.

10. Requirements of powered equipment

Powered equipment, e.g., rotary brush cutters and certain scarifiers, requires sufficient and constant hydraulic power for proper functioning. This must not compromise the normal hydraulic functions and power requirements of the prime mover.

Required properties: sufficient and constant hydraulic flow even at very slow travel speeds; sufficient engine power to overcome added power loss from hydraulic pumps.

SILVICULTURAL PRIME MOVERS USED IN NORTH AMERICA AND EUROPE

North America

Two main types of vehicles are used in silvicultural operations in North America: rigid-tracked tractors (bulldozers) and wheeled skidders (cable and grapple). These vehicles were developed for road building and logging operations, respectively, and were not designed for silvicultural work. This can create problems of compatibility (Ryans 1984).

The bulldozers most commonly used in site preparation have a net flywheel power between 100 and 250 kW, with operating weights of 14 000 to 33 000 kg; others have as little as 30 kW net flywheel power. Maximum capabilities of tractive effort[1] range from 250 to 600 kN. Maximum travel speed is usually 10 to 12 km/h. Ground clearance is between 300 and 500 mm. Hydrodynamic transmissions (i.e., torque converter and powershift gearbox with three or four forward gears) are most common. Some mechanical direct drive transmissions with five or six forward gears are also available.

Wheeled skidders, in the size classes used in site preparation, range from 70 to 150 kW net flywheel power (SAE) with operating weights from 7 000 to 14 000 kg. Maximum capabilities of tractive effort range from 90-kN to 225 kN. Maximum travel speed is 20 to 35 km/h. Ground clearances are from 500 to 600 mm. Hydrodynamic transmissions (torque converter plus power shift gearbox with three or four forward gears) are most common, but direct-drive powershift (eight forward speeds) and mechanical transmissions with four- or five-speed syncromesh and a two-speed transfer case are also manufactured.

Hydrostatic transmissions with mechanical transfer case are available in some harvesters and in specially designed brush cutters.

Other types of prime mover are used for silvicultural work but in much smaller numbers:

Type of prime mover	Example and use
Flexible-track skidder	FMC skidder with front-mounted six-way blade for site preparation on steep slopes
Wheeled forwarder (four-wheel drive)	Franklin Pulpjack with Tecnoma ground herbicide sprayer
Wheeled forwarder/ clambunk skidder (six-wheel drive, rear bogie)	modified Bombardier/Valmet skidder pulling a TTS-35H disk trencher

[1] Tractive effort is the available torque at the wheels divided by the torque lever (rolling radius of the tire or drive sprocket). The torque from the engine is increased through the transmission gearing, torque converter (in hydrodynamic transmissions), differential, and final drive. The available torque is determined after powertrain friction losses are taken into account.

Type of prime mover	Example and use
Harvester	modified Koehring Shortwood Harvester pulling barrels and chains
Integral, self-propelled, special design machines	Letourneau Crusher for site preparation; Shar 20 brush cutter for site preparation or precommercial thinning
Agricultural tractor	typical agricultural tractor pulling small tree planter on afforestation operation
All-terrain vehicle (wheeled or track-type)	Grizzly 16-wheeled vehicle used in seedling transport

Europe

In the Nordic countries, the six- or eight-wheeled forwarder is the most common prime mover, but North American or Swedish cable skidders are also used to pull wing plows in wet soils (Appelroth 1976), and excavators are used on a limited scale for patch scarification in very difficult conditions.

Forwarders of Swedish or Finnish manufacture are available in a range of sizes. Those used in thinning have power ratings of 55 to 75 kW DIN, weights of 6 500 to 8 500 kg, and load ratings of 6 to 8.5 tonnes. Transmission types include mechanical, hydrodynamic, hydrostatic/mechanical, and, as in the Norcar 480 forwarder, pure hydrostatic (i.e., hydraulic motors mounted on wheel hubs).

Large forwarders for final logging are used in site preparation. Power ratings vary from 80 to 151 kW DIN, operating weights from 8 500 to 16 000 kg, and load capacities from 8.5 to 18 tonnes. Maximum capabilities of tractive effort range from 90 to 250 kN, but those in the 120- to 160-kN range are the most common in the 10- to 15-tonne load class. A wide variety of transmission types is available, including mechanical with eight speeds, hydrodynamic with powershift and four to six speeds, and hydrostatic/ mechanical with a two- or three-gear transfer case. Maximum travel speed is normally 25 to 30 km/h. Ground clearances are from 500 to 700 mm. Both six- and eight-wheel drive forwarders exist with bogies at the rear only or at both the front and the rear.

PRINCIPAL DESIGN FEATURES OF AVAILABLE PRIME MOVERS

All of the desirable properties listed under the elements of the duty cycle section cannot be found in any one off-the-shelf vehicle. Some of the reasons for this are as follows: (a) most prime movers currently used in silvicultural work were designed for another use, e.g., for road building or the primary transport of wood; (b) the designer is faced with a number of compromises when designing an off-road vehicle, (e.g., trying to achieve high ground clearance while maintain-

ing a low center of gravity for good lateral stability); and (c) a prime mover must be cost competitive, but as a machine becomes more specialized and/or versatile it also becomes more expensive.

It should be noted that each particular operation, tool, and site dictates the need for, or increases the importance of, certain properties. Nevertheless, the available prime movers have some characteristics that make them suitable for various silvicultural operations.

Running gear

One of the main differences among the three basic types of prime mover is the type of running gear used. Bulldozers have rigid tracks, skidders have single wheels, and forwarders have wheels on bogies with or without bogie tracks.

In adverse terrain with poor ground bearing strength, tracks have better traction and may lose less power from slippage. Tracks offer greater ground contact area than do single wheels, giving lower ground bearing pressure per unit of weight and, therefore, less sinkage and better flotation. Flexible tracks follow the contours of the ground better than do rigid tracks, ensuring greater ground contact area in rough terrain. However, high power losses are associated with tracks because of friction and the weight of the track and its mechanism.

Rigid-tracked vehicles were designed for travel on prepared surfaces. In silvicultural operations, such as disking on obstacle-free terrain, track wear may not be a problem, but pulling barrels and chains on bouldery or obstacle-heavy, undulating terrain creates high bending stresses that cause increased wear on tracks and rollers.

The ability of a vehicle to develop traction is determined by its weight, its running gear, and ground conditions (Table 2). On a typical forest soil, the friction coefficient can range from 0.4 to 0.6 with bogie tracks and from 0.2 to 0.5 with rubber tires. On a dry, clay loam, tracks and rubber tires have friction coefficients of 0.9 and 0.55, respectively.

Table 2. Coefficients of friction for different ground conditions and running gears.

Ground condition	Running gear				Source
	Rubber tire	Tire with chains	Bogie tracks	Tracks	
Quarry pit	0.65	–	–	0.55	Caterpillar 1983
Clay loam, dry	0.55	–	–	0.90	–"–
Clay loam, wet	0.45	–	–	0.70	–"–
Sand, dry	0.20	–	–	0.30	–"–
Sand, wet	0.40	–	–	0.50	–"–
Forest soil	0.2–0.5	0.2–0.6	0.4–0.6	–	Malmberg and
Gravel, loose	0.3–0.4	0.3–0.5	0.4–0.6	–	Granström 1978
Pasture	0.3–0.6	0.3–0.7	0.4–0.7	–	–"–

Chains can improve traction while providing protection to tires from wear by reducing slippage and removing tires from direct contact with the ground. Wheels on bogies provide high contact area while enabling the use of smaller, narrower tires. This is important in Nordic forwarders, on which tires of larger diameter would decrease bunk capacity and raise the center of gravity. As well, tire width is restricted by maximum vehicle width regulations. When equipped with tires of similar size, a bogie axle will deflect less than a single axle when traveling over an obstacle, thereby improving ride comfort (Zylberstein 1982).

Bogie tracks greatly increase flotation by lowering ground pressure; they also improve traction. Among their disadvantages are their high cost and complexity. Also, greater tractive effort is required because of added friction and weight. Moreover, legal road restrictions may require their removal prior to "walking" the machine between sites unless a bogie lift is used.

Tire size is an important consideration in site preparation. Larger diameters can increase ground clearance. In addition, the "footprint area"[2] increases as either diameter or width increases. Increasing the footprint area can reduce sinkage and rutting and can increase usable drawbar pull.

The Forest Engineering Research Institute of Canada (FERIC) has investigated the use of soft, high-flotation tires in both skidding and site preparation (Mellgren and Heidersdorf 1984, Heidersdorf and Ryans 1986). Such tires increase lateral stability, improve ride comfort, and reduce rutting and destruction of advance regeneration, while offering fuel savings. They may also be used on skidders for scarifying terrain with poor ground support capacity.

The rolling resistance of a driven tire is affected by vehicle weight, tire hysteresis, friction, and ground conditions (Table 3). For example, the more a tire sinks, the greater the rolling resistance as the machine constantly tries to climb out of its own rut. Rolling resistance force is calculated from the gross vehicle weight, the coefficient of rolling resistance, and the rate of acceleration (e.g., 9 000 kg x 0.12 x 9.81 m/s^2 = 10.6 kN force). The magnitude of the rolling resistance force is important since it affects the effort required to pull or push an implement, to climb grades, and to push or climb over obstacles.

Table 3. Influence of ground condition on coefficient of rolling resistance for a wheeled vehicle (**after** Malmberg and Granström 1978).

Ground condition	Coefficient of rolling resistance
Asphalt	0.01 – 0.02
Gravel, hard	0.02 – 0.05
Gravel, loose	0.05 – 0.10
Pasture, stone–free	0.06 – 0.10
Forest land, stone–free	0.06 – 0.09
Forest land, stony	0.09 – 0.12

[2] For simplicity, the nominal (rated) footprint area of a tire can be approximated by D/2 x W, where D = diameter and W = width; the expression assumes a sinkage of 7% of the outer tire diameter.

Steering

Two forms of steering can be found in prime movers used in silvicultural work: skid steering in tracked vehicles and articulated steering in wheeled vehicles. Both types are effective in off-road applications, but a skid-steered vehicle does not have the ability to "duck walk" off an obstacle once it has become hung up, whereas an articulated vehicle does.

"Off-tracking" is influenced by the type of steering and by vehicle dimensions. In skid steering, the rear of the machine may not cover the same path as the front, especially in sharp turns. In articulated machines, the amount of off-tracking of the rear wheels will depend upon the location of the steering joint in relation to the wheel base, the length of wheel base, and the degree of turn. Off-tracking might have an important influence on the amount of damage inflicted on residual trees in commercial and precommercial thinnings. Off-tracking is also consequential in mechanized tree planting, where a front-mounted plow on a tracked tractor prepares the planting spot for a towed planter.

Vehicle weight

Weight is an important factor in determining the traction and usable drawbar pull. Heavy, tracked vehicles are able to use the high tractive effort that they produce because of their weight. For example, a 224-kW tracked tractor may have a weight of 32 000 kg and produce a tractive effort of 225 kN at 40 m/min. The usable drawbar pull determined by vehicle weight and soil condition (friction coefficient of .70) is 219 kN. In comparison, a 10 000-kg, 90-kW wheeled skidder may have a technical tractive effort of 90 kN at 60 m/min (0% slope), but the usable pull (if we assume a friction coefficient of 0.60 with tire chains) is only 59 kN. Reference, in Table 1, to the drawbar pull requirements of various implements shows clearly why a heavy vehicle is needed to pull a set of barrels and chains.

Weight also increases the grade resistance force, which decreases the drawbar pull available to the implement. The grade resistance force is equal to the sine of the grade angle (α) times the gross vehicle weight. A 20% slope ($\alpha = 11.3°$) results in grade resistance of 61 kN and 19 kN for the above-noted tracked vehicle and skidder, respectively.

If a rolling resistance coefficient of 0.10 is assumed for the wheeled skidder, the force required to overcome rolling resistance is 9.8 kN. The grade resistance force for the same skidder and a 2500-kg implement is 24.0 kN. Hence, the total resistance is 33.8 kN, excluding the drawbar pull (draft) requirement of the implement. The usable pull is 57.7 kN on a 20% slope. This leaves an available drawbar pull of 23.9 kN on the skidder to pull a 2500-kg implement. Referring to Table 1, and comparing the mean drawbar pull requirements of a Bräcke, one can understand why the 90 kW skidder, while traveling upslope, is very sensitive to any extra resistance (e.g., a stump) or loss of ground strength, and why a quick-release hitch is needed. With a disk trencher, the skidder would already have stopped or begun to spin its tires on a lesser slope.

Transmission

Three major types of transmission can be found in the available prime movers. Each has advantages and disadvantages, depending on the application.

Briefly, mechanical transmissions (mechanical gearbox and direct drive with powershift) have low power losses in relation to the other types of transmission, and transmit more of the engine power to the running gear. Mechanical transmissions require a high number of gears to keep the engine delivering maximum power. Generally, eight or ten speeds are available. Disadvantages are that such a transmission is tiring to operate (if not power-shifted), and a skilled operator is required.

Hydrodynamic transmissions use a fluid coupling (torque converter) between the engine and a powershift gearbox. The main advantage of a torque converter is that the available torque is automatically increased when the machine is about to start or when it is overcoming a large driving resistance. In this way each gear gets a wider working range, and fewer gears are required than in a mechanical transmission (Malmberg and Granström 1978). However, it is necessary to keep the torque converter working at a speed of maximum efficiency. At low site-preparation speeds, there may not be enough gears in the low range, and this would result in low torque converter operating efficiency. North American skidders have only three or four speeds, whereas Nordic forwarders have up to six speeds.

Hydrostatic transmissions use the power of a liquid under high pressure and low flow velocity, whereas hydrodynamic transmissions use the kinetic energy of a liquid (i.e., high flow velocity but low pressure). In hydrostatic transmissions, high efficiency, variable displacement pumps, and variable or fixed displacement motors replace the torque converter coupling of hydrodynamic transmissions. The practical implications of this are that, in comparison with hydrodynamic transmissions, a much slower and steadier speed can be maintained with peak power, and fewer gears are needed to get the required speed range. The wheels rotate at the selected speed up onto obstacles and down the other side, and this results in a more even speed and a more comfortable ride for the operator. In contrast, the increased resistance presented by an obstacle slows a vehicle equipped with a torque converter, causing increased torque in the converter and the generation of heat; when the wheel reaches the top of the obstruction, the machine increases speed rapidly as there is no braking effect in the hydrodynamic transmission and, consequently, the prime mover bounces down from the obstacle. Another advantage of the hydrostatic transmission is that the engine is always running at a selected rpm and is independent of driving speed. This is important for powered equipment, such as brush cutters and powered scarifiers, because the implement receives the required flow at all travel speeds.

Ergonomics

Ergonomic factors influence machine productivity. Since the operator controls the speed of travel, the operator's well-being influences average ground speeds. An operator's limitations may prevent the machine from reaching its cruising speed, even if the prime mover has enough power and traction. Ergonomic stress will cause an operator to reduce ground speeds and will aggravate fatigue, and may initiate long-term health problems.

The ergonomic characteristics of a prime mover influence the ease with which skilled operators can be attracted and retained. A two-way radio is important for reasons of safety and for reducing downtime, especially in site preparation operations, which quite often are far removed from regular harvesting operations.

Cabs of Nordic forwarders generally are ergonomically favorable because of strict government regulations and the tendency of operators to remain in the cab during the entire shift.

Most cable skidders have poor cab ergonomics for continuous site preparation operations. For skidding, the operator is constantly in and out of the cab to load and unload. Heaters, enclosed cabs, air conditioners, and plush fabric on the seats are therefore not practical.

CONCLUSION

A variety of vehicles is available in Europe and North America, but most of those used in silvicultural work were designed primarily for another use. Moreover, for economic reasons, a large percentage of the prime movers used in silvicultural operations will continue to be multipurpose machines. Therefore, a basic understanding of the advantages and disadvantages of certain design features and of vehicle/soil/site relationships is important to the forest manager selecting a prime mover and matching equipment for a particular operation on a particular site. A thorough understanding of the nature of the duty cycle is necessary for the engineer to design a prime mover primarily for stand establishment.

LITERATURE CITED

Appelroth, S. E. 1976. Site preparation in Scandinavia. **Forestry Chronicle** 52:133-136.

Calvert, W. W. and Garlicki, A. M. 1970. Skidding forces and power requirements. Department of Fisheries and Forestry, Canadian Forestry Service, Ottawa, Ontario Publication No. 1279, 25 p.

Caterpillar 1983. Caterpillar performance handbook, 14th ed. Caterpillar Tractor Co., Peoria, Illinois, 552 p.

Dalström, J. 1974. Dragkraftsbehov vid markberedning. Forskningsstiftelson Skogsarbeten, Stockholm, Teknik Nr. 6, 4 p.

Gustafsson, J. and Morenius, B. 1980. Wadells markfräs. Forskningsstiftelsen Skogsarbeten, Stockholm, Teknik Nr. 4, 6 p.

Heidersdorf, E. and Ryans, M. 1986. Joint FERIC/MER high-flotation tire trials Quebec, 1984. Forest Engineering Research Institute of Canada (FERIC), Montreal, Technical Report TR-64, 45 p.

Heikurinen, J. K. K. 1975. Powered vs nonpowered site preparation equipment. p. 37-46 *in* Mechanization of Silviculture in Northern Ontario. Department of Environment, Canadian Forestry Service, Sault Ste. Marie, Ontario, Symposium Proceedings 0-P-3.

Malmberg, C. E. and Granström, L.. 1978. Terrängmaskinen. Del. 1. Forskningsstiftelsen Skogsarbeten, Stockholm, 507 p.

Mellgren, P. G. and Heidersdorf, E. 1984. The use of high flotation tires for skidding in wet and/or steep terrain. Forest Engineering Research Institute of Canada (FERIC), Montreal, Technical Report TR-57, 48 p.

Ryans, M. 1984. Prime movers in silvicultural practice. Forest Engineering Research Institute of Canada (FERIC), Montreal, Technical Note TN-79, 16 p.

Zylberstein, M. 1982. Maskinerna skakar-vad kan vi göra at det. Forskningsstiftelsen Skogsarbeten, Stockholm, Resultat 8, 4 p.

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SESSION III - SILVICULTURAL PRESCRIPTIONS

SILVICULTURAL PRESCRIPTION FOR STAND ESTABLISHMENT: BIOLOGICAL CONSIDERATIONS

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KEYWORDS: silvicultural prescription, rule-based inference systems, constraints, wind, atmospheric constraints, edaphic constraints, soil temperature, biotic constraints, harvesting

INTRODUCTION

The term "silvicultural prescription" is a relative newcomer to forestry terminology. It appears in neither Ford-Robertson's (1971) "Terminology of Forest Science, Technology, Practice and Products" nor Ruokonen's (1984) "Forestry and Forest Products Vocabulary". Ford-Robertson recognizes the term "prescription" only in relation to yield determination. The first of the six meanings given by the Oxford English Dictionary (1971) is the most appropriate in a silvicultural context: "the action of prescribing or appointing beforehand; that which is prescribed or appointed; written or explicit direction or injunction". I would therefore propose the following definition:

> **silvicultural prescription** (n.). A schedule of specific silvicultural measures intended to achieve, on a given site, a defined management objective or set of objectives.

Thus, a silvicultural prescription for stand establishment is a schedule of measures intended to transform the existing vegetative cover of a given site into one that includes an established stand of crop trees compatible with the objectives of management.

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In this paper, after a discussion of biological soundness in silvicultural prescription, examples of constraining factors -- atmospheric, edaphic, and biotic -- are listed. One constraint in each class is discussed in detail, under (a) biological effects, (b) controlling factors, and (c) prescriptive amelioration, to illustrate the considerations upon which silvicultural prescriptions should be based. Finally, an increased role is suggested for rule-based inference systems in helping the silviculturist to gain access to and use the relevant part of the vast existing store of information.

BIOLOGICAL SOUNDNESS

Biological soundness in a silvicultural prescription derives not from any attempt to guarantee success at any price, but from (a) the accurate identification of constraints likely to depress unacceptably the performance of the chosen regeneration stock, and (b) the amelioration of these constraints by the prescribed treatment(s) to levels that, in the absence of unusually severe stress, are sufficient to secure the performance required by the objectives of management.

The soundest of silvicultural prescriptions will fail biologically in the face of extreme aberrations in weather, insect epidemics, etc. Even if it were possible to anticipate all such eventualities, attempts to formulate prescriptions to overcome them would be excessively expensive. Hence, prescriptions are generally formulated within the context of normal levels of the normal suite of constraints.

Within those limitations, prescriptions should seek to achieve objectives as efficiently as possible, for, apart from any other consideration, efficiency and biological soundness go hand in hand. As Sydney Smith (1771-1845) noted: "We move most quickly to that point where we wish to go." Similarly with plants, vigor of growth and development are most readily promoted when the biological predispositions of the plants are reinforced.

Prescriptions are formulated to achieve objectives. Therefore, the objectives must be biologically attainable. They must also be biologically reasonable: for example, although it may be technically possible to grow teak (*Tectona grandis* L.f.) in northern Ontario, to do so would be biologically unreasonable and economically disastrous. This underlines the inevitability of biological and economic interaction at every level from initial formulation of policy to eventual implementation of a prescription. However, the biological aspects of stand establishment are decisive (Buss 1980).

The objectives formulated for a given site must be compatible with the overall objectives of management, and they must be specific enough to give clear direction to the prescription for that site. Unless the objectives are clear, the logical basis for devising particular silvicultural treatments is eroded, and progress cannot be evaluated.

To determine how the objectives might be attained, the prescriber must inventory the constraints that could be expected to jeopardize the attainment of the objectives for that particular site, and then devise treatments to reduce those constraints to acceptable levels.

CONSTRAINTS ON TREE PERFORMANCE

In the field, constraints always depress tree growth below the genetically determined potential. Optimum conditions for growth, if they occur at all, are never prolonged. Even the performance of irrigated agricultural crops in benign climates varies from year to year (Decker 1985).

The relationship between constraint and growth (or, more commonly, between constraint and yield) has been debated for at least 150 years. What became known as the **Law of the Minimum** was formulated by Liebig in 1843: the relationship between yield and growth factor level was assumed to be linear (Liebig 1843). A succession of investigators, including Mitscherlich (1909, 1928), subsequently rejected the linearity of the relationship: any linearity is approached only over a short section of the curve where growth or yield is limited by extreme deficiency of a single growth factor. Though not defensible as stated, the **Law of the Minimum** nevertheless provided the conceptual basis for the **Principle of Limiting Factors**: "The level of crop production can be no greater than that allowed by the most limiting of the essential growth factors" (Buckman and Brady 1969).

Quantification of individual or multiple growth constraints in forestry is generally possible only in broad terms; but the essential task of the formulator of a silvicultural prescription for stand establishment on a particular site is to identify and evaluate the suite of constraints that, in the absence of amelioration, would probably frustrate the objectives of management.

For regeneration stock to develop satisfactorily toward stand establishment, ameliorative treatment of a great variety of constraints may need to be considered. Constraints can be conveniently grouped into three classes: atmospheric, edaphic, and biotic (Table 1). Most of these constraints are complexes rather than single factors, and there are many interactions.

Table 1. Factors that commonly constrain tree performance.

Class of constraint		
Atmospheric	Edaphic	Biotic
Wind	soil depth	harvesting residue
Air temperature	soil temperature	competition
Radiation	soil moisture	pest fauna
Humidity	soil texture	harvesting[a]
Precipitation	soil structure	site preparation[a]
	soil bulk density	regeneration stock[a]
	soil fertility	tending[a]

[a] inappropriate method or execution

Discussion of all aspects of all major constraints, and full examination of the biological effects, controlling factors, and prescriptive amelioration and accommodation, are beyond the scope of this paper. Instead, one example from each of the atmospheric, edaphic, and biotic classes will be examined in detail.

Atmospheric constraints

The distribution of forest vegetation and the zonal and regional differences therein are climatically determined. Within any climatic province, however, the regeneration silviculturist must also be concerned with the short-term variation in weather, variation that is largely ironed out with respect to the climatic time scale and may be inconsequential for established vegetation. It is the immediate day-to-day weather near the ground that determines the fate of regeneration stock. This weather is the product of highly complex interactions among meteorological factors, vegetation, soil, and topography (Geiger 1950, Odin 1979a, b, Houghton 1985). The atmospheric constraint considered here will be **wind**.

Wind (i) Biological effects

Air movement affects vegetation both mechanically and physiologically. Wind may be a crucial factor in the critical stage of forest establishment (Spurr and Barnes 1980).

Mechanically, outplants may be destabilized by socketing and twizzling (Sutton and Tinus 1983) or by wind erosion of dry, non-cohesive soils, especially those that have been exposed by cultivation or elevated above their surroundings by mounding or ridging. Pines (*Pinus* spp.) generally are more vulnerable to destabilization than are members of other common forestation genera.

The foliage and buds of regeneration stock may be damaged by the whipping action of other vegetation. Such injury will reduce photosynthetic capacity, increase water loss, and decrease growth potential. Laminar flow of air and turbulence are both important in this respect. In any given situation, injury increases with air movement.

A beneficial effect of wind sway of outplants has also been reported. Large red pine (*Pinus resinosa* Ait.) stock outplanted on sites highly susceptible to frost heaving escaped heaving by virtue of being isolated by socketing from the frozen, heaving surface soil (Schramm 1958).

Mechanical damage can also cause tracheid embolism in hardwood regeneration stock of ring porous species, with consequent reduction of water-conducting capacity (Fitter and Hay 1981).

Physiologically, the chief importance of wind is its effect on evapotranspiration and on leaf energy budgets. Exposure to wind aggravates moisture stresses in the plant and in the soil. The drier surface conditions after harvesting (Hendrickson et al. 1985) are particularly important for young seedlings. Together with the mechanical effects of exposure, these conditions can halve the productivity of established forest (Loucks 1966). Dwarfing and stunting are typical responses to severe exposure (Bidwell 1979). The contouring of crowns by wind is most readily observed in hedgerow trees, but the effect is omnipresent wherever differential exposure occurs. For regeneration stock, the stresses are particularly severe because of the small internal reserve of moisture and the generally deficient root system before establishment. These stresses are intensified when compounded by others, notably those deriving from soil moisture deficits. Moisture stress reduces photosynthetic capacity directly and, by contributing to the senescence and dehiscence of the older foliage, indirectly. Growth, including root growth, is slowed and the vulnerable pre-establishment phase is prolonged.

Not to be lightly discounted is the biological damage that can be done during handling and planting operations, especially to bare-root stock, when root systems are exposed, albeit briefly, to wind (Mullin 1974). High windspeed and low atmospheric humidity are a dangerous combination.

At low windspeeds, up to about 2.2 m/sec (Wadsworth 1959), photosynthesis is enhanced modestly by virtue of improved supply of carbon dioxide to foliage.

Windspeed determines the energy lost by plant leaves by convection of heat, an important factor in controlling the thermal balance of the plant. Incident radiation surplus to photosynthetic requirements is converted into heat energy, which must be dissipated if excessive elevation of temperature is to be avoided. Convection is one of three major processes acting to remove heat from the foliage of well watered plants, longwave radiation and transpiration being the others (Fitter and Hay 1981).

Wind has other biological effects in that it is the vehicle for the dispersal of forest tree seed of many species and thus influences the number and distribution of seed trees required for natural regeneration systems. Seed-tree stability is also markedly influenced by the interaction of wind with other site factors and with the trees themselves.

Windspeed also largely determines the disposition of snow cover. In some regions, this has important consequences with respect to snow mold, soil moisture, soil temperature, damage to regeneration stock by small mammals (Odin 1979a), and overwintering of nursery stock.

Sand- and ice-blasting damage to regeneration stock can be limiting constraints in exposed situations.

Wind: (ii) Controlling factors

Windspeed is controlled by differences in atmospheric pressure influenced by topography and surface drag. Turbulent flow -- a state of movement of a fluid in which the velocity (direction as well as magnitude) of the fluid varies in more or less random fashion (van Wijk and Borghorst 1966) -- predominates near the ground. Turbulent air is therefore more active than non-turbulent laminar flow in both the physical and the biological senses. Factors promoting turbulence include differential heating and cooling and surface irregularities, vegetational as well as topographic. The degree of irregularity can be expressed by the logarithmic wind law **roughness factor** (z_o), the marked influence of which is illustrated by Odin's (1979a) example: light (7.5 m/s) and moderate (15 m/s) windspeeds at 50 m above ground level were experienced at the 1-m level as winds of 3 m/s and 5.5 m/s, respectively, when z_o = 10 cm, but only as winds of 1 m/s and 2 m/s, respectively, when z_o = 50 cm. Hence, windspeed and snow cover can be influenced greatly by harvesting and site-preparation treatments. The effect diminishes to insignificance in cutovers larger than about 30 ha (Odin 1979a). Within a clearcut, the influence of the shape of the harvested area and its relationship with surrounding vegetation and topography may be great (cf. Alexander 1964). These aspects of windspeed variation are important principally through the control they exert on evapotranspiration by influencing the thickness of the boundary layer, that relatively undisturbed layer of air at the leaf surface through which water must diffuse as vapor before it reaches the bulk air. With a bulk windspeed of 1 m/s, the thickness of a boundary layer might be about 1 mm, although the value would vary with leaf size and shape (Fitter and Hay 1981); in typical mesophytes, the resistance of the boundary layer to the diffusion of water vapor decreased to little more than one tenth when the bulk air windspeed of 10 m/s decreased a hundred times to 0.1 m/s. At very low windspeeds, the boundary layer resistance might control transpiration rates over a range of stomatal apertures (Bange 1953).

The control exerted by windspeed on convectional heat loss from leaves is described by the second of three terms in the equation derived by Gates (1976) for partitioning the energy budget of plant leaves:

$$\text{energy lost by convection of heat} = k_1 (V/D)^{0.5} (T_l - T_a)$$

where k_1 is a constant, V is windspeed, D is leaf width, and T_l and T_a are the temperature of leaves and bulk air, respectively.

The factors controlling mechanical aspects of wind constraint are largely self evident. With regard to twizzling, however, contributory factors should be mentioned. Pines, though often quick in youth to develop a crown that is large in relation to the ability of the outplant's root system to support it, generally have a limited ability to form adventitious long roots from the root-collar region after outplanting. The nature of the soils on which pines are commonly planted also contributes to twizzling.

Wind: (iii) Prescriptive amelioration and accommodation

Where wind constraints are identified as serious, prescriptions should require any harvesting and all site preparation treatment to minimize increase in windspeed at regeneration stock level. Hence, clearcuts must be small, preferably in strips in the lee of standing forest. Consistent with the need to reduce any other significant constraints to acceptable levels, site preparation should maximize the roughness factor; shelter may be created for regeneration stock by ground configuration. In exceptional cases, individual shelters for regeneration stock might be prescribed. Sheltered seedspots can be superior to outplantings, especially if pine is the genus of choice and if long-term stability of the stand is questionable. If bare-root regeneration stock is to be used, extra care in handling and planting should be prescribed. Deep planting (Sutton 1967) may be required to improve resistance to socketing.

Edaphic constraints

"Soil properties, like pH, stonyness (*sic*), moisture, humus, and bacteria content, are variables designated by the letter s as s_1, s_2, s_3, ... etc. The number is very large and many of the properties are interrelated. When one of them changes, many others also assume different values" (Jenny 1980). Soil temperature is no exception.

Soil temperature: (i) Biological effects

Temperatures within the rooting zone virtually determine the temperature of the roots therein, although the metabolic activity of roots will tend to elevate root temperatures slightly with respect to adjacent soil. Soil temperature powerfully influences plant growth (Richards et al. 1952, Cooper 1973). Effects vary with species, physiological state, and many other variables. Constraints can be imposed by temperatures that are too high or too low.

Damaging high temperatures are generally confined, at least in boreal and temperate conditions, to seedlings and young plants, the succulent stems of which are in contact with highly

insulated surface soil of low heat conductivity: this usually implies that an overstorey has been removed in the recent past. The period immediately after emergence is particularly hazardous for seedlings; brief exposure to surface soil temperatures of 55°C or more is commonly fatal (Li 1926). Direct insolation in summer often produces surface temperatures of 70°C at midday, even at high latitudes (Vaartaja 1954). Prolonged exposure to temperatures of 35-40°C will kill most plants (Bidwell 1979). The direct effect of high temperature is to denature and coagulate proteins, but an important side effect is the accompanying exacerbation of plant water stress (Bidwell 1979).

Soil surface temperature indirectly influences plant growth through its effect on the atmospheric climate near the ground (Geiger 1950). The elevation of atmospheric temperature does not normally constrain the functioning of the aerial tissues of plants, but the effect depends very much on the internal moisture status of the plant.

Low soil surface temperatures increase the chance of frost damage to aerial tissues and are associated with frost heaving, a major cause of seedling mortality (Schramm 1958, Heidmann 1976). The severity of frost heaving varies from year to year and from one episode to the next; sometimes the forces generated are strong enough to uproot vigorous, apparently well established, stock several years after outplanting (Sutton 1968). Through the action of frost heaving, parts of root systems may be naturally root-pruned annually for many years (Sutton 1969). Cold surface soil delays germination of seed and limits seedling root growth (Adams 1934).

Within the soil, the incidence and severity of freezing stress with respect to tree roots in forested conditions are largely unknown (Levitt 1980). Orlov (1957), however, has provided direct evidence that short roots of Norway spruce (*Picea abies* [L.] Karst.) can live for several years in nature. This suggests that freezing stress may be rare in forested conditions, even in the boreal forest. Nevertheless, although evidence seems to be lacking, such damage to roots may be common and severe in boreal winters in soil unprotected by vegetation cover, organic forest floor, or snow. The biological effects of freezing commonly derive from the extracellular formation of ice in intercellular spaces, with consequent freeze-dehydration of intracellular contents; when freezing is sufficiently rapid, ice can form within cells, and this is almost always immediately fatal to those cells (Levitt 1980). For any hardy tissue, there would seem to be a critical zone of freezing temperatures, above and below which the effects on the plant are independent of the rates of cooling and warming, but within which rates are consequential (Levitt 1980).

Chilling stress (Levitt 1980) from low, but not freezing, soil temperatures is undoubtedly widespread in boreal conditions, especially with exposed soils of high heat capacity, which require large inputs of heat before they warm up in spring. The main effect of low soil temperatures is on water relations. Aside from deficient soil moisture, low soil temperature is probably the most important environmental factor affecting the rate of water absorption (Kramer 1940).

At low soil temperatures, water is relatively viscous; the movement of water through both soil and root is impeded, an effect reinforced by a decrease in the permeability of membranes and protoplasm at low temperatures. Uptake of water (especially that part of uptake requiring the expenditure of energy from respiration) and mineral nutrients (especially uptake counter to a concentration gradient) are inhibited, albeit to different degrees in different species (Döring 1935, Kramer 1942).

Phosphorus (P) nutrition in particular severely affected, and high levels of soil P do not overcome the problem (Knoll et al. 1964). The energy level required for uptake of P might exceed that which can be generated at low rates of respiration. Root growth will be inhibited in these circumstances, as will germination.

These restrictions on uptake are especially serious for newly outplanted stock that has yet to establish good root/soil contact and develop a root system appropriate to the tree in its new situation, more particularly when insolation and transpirational stresses are high. When transpirational stress is high, mortality rates may be 100% among trees outplanted in cold, wet soil in the spring (Sutton 1968).

Soil temperature: (ii) Controlling factors

Direct shortwave insolation is the primary source of heat influencing soil temperature. The changing intensity of this radiation is the principal cause of the temperature variation at the soil surface (van Wijk and de Vries 1966). In general, the amounts of diffuse and thermal radiation reaching the soil surface are much smaller than the amount of shortwave radiation, although, in a very cloudy climate, as much as 80% of the total solar radiation received may be diffuse (Gates 1965).

The intensity of the direct insolation on a horizontal area of the earth's surface is determined by solar altitude, terrestrial latitude, solar declination, solar hour angle, radius vector of the sun-to-earth distance, and the transmission coefficient of the atmosphere (Gates 1965). The proportion of solar energy absorbed by passage through the atmosphere is greater at higher than at lower latitudes because the angle of incidence of incoming sunlight is more acute at the higher latitudes (Tamm 1950).

A difference in latitude of 10 degrees can change the direct radiation falling on a horizontal plane by as much as 30%. Seasonal radiation intensity can differ by a factor of three. Aspect strongly influences the amount of insolation on a piece of ground (Fox 1985): a 1-degree slope to the north (or south) is equivalent, in terms of insolation, to flat ground 100 km further north (or south) (Shul'gin 1965). The intensity of direct insolation on slopes can be estimated by applying the cosine law to the horizontal surface radiation (Gates 1965).

Some of the radiation on a soil surface is reflected. Shortwave reflectance may range from 85% for fresh snow to 2% for wet, dark clay; most vegetated surfaces have reflectance coefficients of between 10 and 25% (van Wijk and Scholte-Ubing 1966).

Received radiation that is not reflected is absorbed and changed into thermal energy (Cochran 1969). Absorption of radiation of any wave length takes place at the receiving surface; in soil, absorption occurs in a layer a fraction of a millimetre thick (van Wijk and de Vries 1966, Voorhees et al. 1981). Reflectance and absorption factors vary with wave length, but this is of minor importance in relation to the heat balance of the surface. Re-radiation at long wave lengths varies with temperature (Geiger 1950).

Heat flow through soil is controlled by the soil's apparent thermal conductivity and by temperature gradients (Sepaskhah and Boersma 1979). The apparent thermal conductivity is a function of the thermal properties of the solid materials, soil texture, pore size distribution, water content, and temperature of the medium. Heat flow occurs by conduction through the solid particles, through the water films coating the particles and the water annuli at the points of contact between particles and, to a much lesser extent (van Wijk and de Vries 1966), through the air in the soil pores. Heat also moves by vapor diffusion from relatively warm regions to cooler regions, where the vapor condenses. Water in liquid form may move in response to surface tension differentials caused by temperature differences, since surface tension decreases with increasing temperature.

Moisture in the soil has two major influences on temperature relations. First, it increases the heat capacity per unit volume. The heat capacity of dry soil varies with the character of the soil, but is much lower, and may be half (Chirkov 1979) to 20% (Keen 1932) the heat capacity of water. Under the influence of a given amount of heat, therefore, wet soil increases in temperature less than does drier soil. Second, moisture added to dry soil increases the conductivity of the soil, because although the conductivity of rock is about seven times greater than that of water (Keen 1932), the conductivity of particulate rock is only about 30 to 50% that of water, owing to poor thermal contact between particles. In moist soils not saturated with water, the transport of heat is complicated by the fact that the moisture tends to redistribute itself when the temperature field changes (de Vries 1966). Moisture moves both as liquid and as vapor; both forms transport sensible and latent heat, and this further complicates soil temperature relations.

From the soil surface to the damping depth (Cochran 1969), soil temperature varies diurnally and seasonally; at all depths the temperature roughly approximates a pure harmonic function of time around an average value (van Wijk and de Vries 1966). In a given soil, the damping depth is about 19 times greater for the annual than for the diurnal variation. Commonly, the diurnal variation penetrates not more than 50 cm into the soil, the annual variation not more than 10 m. In many soils, the damping depths are much less.

Thawing and the penetration of frost are complicated cases of heat transmission. Latent heat of fusion is released or absorbed at the soil/liquid interface (van Wijk 1966). The complications include migration of the interface, change in the volume of water when it freezes and of ice when it thaws, segregation of soil moisture under the influence of vapor pressure gradients, and the heaving of surface layers (Portz 1967, Heidmann 1976).

Snow cover has a marked effect on frost penetration. For instance, at Ottawa, Ontario, during the winter of 1950/51, with "an average snow cover for the winter" of about 30 cm, the maximum depth of frost penetration in "sand" was 46 cm under undisturbed snow cover, as opposed to 117 cm without snow; in "clay", the comparable values were 23 cm and 74 cm, respectively (Crabb and Smith 1953, Crawford 1953). Reductions in frost penetration as a result of snow cover have been variously estimated at about 60 cm for each 30 cm of snow (Crawford 1953) and at an amount equal to the depth of the snow (Atkinson and Bay 1940). Even small amounts of harvest residues on the ground surface are effective in trapping snow and thereby reducing the depth of frost penetration; among different tillage systems, percentage residue cover and residue distribution "seemed to have the dominant effect on soil temperature and soil heat flux", more than the differential effects produced in soil thermal properties by the tillage systems themselves (Kay et al. 1985).

Soil temperature: (iii) Prescriptive amelioration and accommodation

If high temperatures at the soil surface have been identified as a constraint requiring amelioration, the most straightforward remedy would be to reduce the amount of shortwave radiation received by the soil surface. This may be done for the site as a whole where there is existing vegetation to manipulate. Retention of part of an overstorey and/or another stratum of the vegetation may be prescribed to provide shade sufficient to modulate surface temperatures to non-limiting levels with respect to the chosen method of regeneration; or bands or patches of shade may be provided through microtopographic ground configuration (although ground configuration is more commonly aimed at increasing the amount of shortwave radiation received and modifying drainage); alternatively, spots already shaded by existing natural features (e.g., stones, hillocks, stumps and logs) may be prescribed for seeding or planting; or artificial shading devices may be provided.

Surface soil temperatures may also be reduced by increasing the heat flow from the surface, e.g., by removing the insulating organic forest floor layer. This would also affect temperatures within the body of the soil, and might have important implications for soil fertility.

Any decrease in volumetric heat capacity and/or heat conductivity through the surface layer would fortify the constraint of high surface soil temperatures. Consequently, cultivation that loosens structure and increases air content (van Wijk and Derksen 1966, Cooper 1973), or mulching that gives similar effects (Radke 1982), will tend to decrease heat transfer from the surface (Potter et al. 1985). In periods of increasing surface temperature, the tilled soil is warmer at and near the surface; below a certain depth, it is cooler than uncultivated soil (van Wijk and Derksen 1966). The converse conclusions apply to a period of decreasing surface temperature.

Where low temperatures in the rooting zone have been identified as a constraint requiring amelioration, the prescriber must recognize that if soil is more easily warmed, it is also more easily cooled. In most instances, however, what is being sought is vernal warming of soil to promote root growth and uptake of water and nutrients among outplants or seedling stock. Two main approaches can be taken, singly or in combination. First, the volumetric heat capacity of the rooting zone soil can be reduced by drainage, either directly by means of drains or indirectly by mounding or other forms of ground configuration. Second, the insulating organic forest floor layer can be removed to increase heat transfer to the soil body when the heat balance is positive.

The possibility of repercussive effects on soil fertility after ameliorative forest floor removal has been mentioned. The prescriber should also be aware of other possible consequences, including increased risk of freezing injury to roots and aggravated frost heaving.

All such conflicts must be evaluated and, as far as possible, resolved with respect to the chosen regeneration stock species. When regeneration is to be by planting, the choice of type, class, and grade of stock and the method (including depth) and season of planting should be made with full consideration of possible side effects from the prescribed treatments. For instance, if the decision has been taken to expose mineral soil with the aim of raising soil temperatures in the spring, and if this would increase the danger of frost heaving, then it might be advisable to prescribe deeper than normal planting (Sutton 1967), large planting stock, or the retention of strips or patches of undisturbed forest floor and root mat. The care with which pros and cons must be evaluated is illustrated by Schramm's (1958) report of successful avoidance of frost heaving, on soil much subject to that phenomenon, by large red pine outplants subject to socketing or twizzling (Sutton and Tinus 1983); the line between avoidance of frost heaving and promotion of toppling must be uncomfortably fine.

Biotic constraints

Harvesting: (i) Biological effects

The vegetation occupying a site, the portion harvested, and the condition of that which is left all have strong biological implications, as do the nature of the forest floor and the kind and degree of disturbance incurred during harvesting operations. The many influences deriving from the harvesting disturbance include: slash density and distribution, accessibility to traversability of the site by people and machines, food and habitat for wildlife and pests, stability

of residual trees, seed production (species and amounts), competitive status and potential of residual and invading vegetation, the climate near the ground, soil fertility and nutrient distribution, soil moisture and infiltration rate, soil bulk density, and soil temperature.

Harvesting: (ii) Controlling factors

The factors that determine the severity and kind of constraint arising from harvesting are largely self evident. System of harvesting (e.g., clearcut, strip, patch, shelterwood, etc.), method of harvesting (e.g., shortwood, tree-length, and full-tree), level of utilization, type of machine, and season and ground conditions at the time of harvesting, in interaction with other site factors, all carry obvious biological implications. A less obvious factor was mentioned by Benzie (1971): full-tree logging may be less effective in removing tops and branches in very cold weather than in normal conditions, especially for species with brittle wood.

Zasada (1971a) has considered various biological consequences of several systems of mechanized harvesting.

Microbiological effects of forest management practices, including harvesting, were reviewed by Hendrickson et al. (1982).

Harvesting: (iii) Prescriptive amelioration and accommodation

The advantages of treating harvesting as part of a cyclic forest-harvest-regeneration-forest system have largely been overlooked in exploitive forestry; with few exceptions, harvesting has been conducted on the basis of minimizing the cost per unit volume of extracted wood. However, as Alm (1971) has emphasized, "mechanization offers considerable opportunity to create conditions during the logging process that will make regeneration efforts easier and more efficien. ...However, emphasis must be placed on planning, so that mechanized logging is not conducted as a separate operation but as an integral part of the overall forest management plan with consideration given to the biological impact on the site and the effect on the future stand."

Zasada (1971b) illustrated a case in point in connection with the problem of unmerchantable trees in clear-cut harvesting of aspen. He noted that, of the unmerchantable stems 2.5 cm in diameter and larger, 65% were broken or uprooted where felling was done manually, but 90% were removed where felling was by machine. If the fate of the unmerchantable component of a stand is not to be left to chance, therefore, it must be prescribed. Treatment of the unmerchantable stems is cheaper "if it is part of the harvesting operation, rather than a follow-up job of knocking down or spraying the residual trees" (Zasada 1971b).

Zasada (1971b) has given another example of the importance of adopting a systems approach rather than treating each operation as an independent event; full-tree logging of pure, fully stocked stands of jack pine (*Pinus banksiana* Lamb.) left sites 90% clear of slash, 80% clear of shrubs, and easily plantable without further site preparation. The tree-length system "will produce conditions similar to the full tree system, except that 30-40% of the cut over area will be covered with slash and not available for planting." Site preparation was even more necessary after shortwood logging; even on sites where there was little or no underbrush before logging, 30-40% of the area was left covered with slash.

In arriving at a prescription representing the most advantageous overall management option, the prescriber must take account of merchantable volume and wood quality, range of merchantable tree size (because uniformity of size facilitates mechanized harvesting); the species, size, and number of unmerchantable trees and whether and how they should be disposed of; the understorey trees and shrubs, as well as the value they may have for wildlife or for soil stability, and what adverse effects they may have; the trafficability of the soil for various kinds of harvesting equipment, the vulnerability of the soil to damage by compaction or erosion, and the fertility level (in order to assess the ability of the site to withstand various levels of nutrient removal in the different systems of harvesting); and topographic limitations to the various systems of harvesting (Benzie 1971). As well as designating the harvesting system and pattern, the prescription must also specify: "the number, size, and location of landings; width and spacing of access trails, season of logging, slash left in the woods, removed, burned or chipped; and treatment of other vegetation, including unmerchantable trees and shrubs" (Benzie 1971).

Specific concerns of the prescriber must be addressed by specific prescriptions. If, for instance, disturbance of the forest floor needs to be minimized, then, where climatically appropriate, the prescription may require logging to be carried out when there is snow cover to a depth of 30-60 cm (Tappeiner 1971). If disturbance of the forest floor needs to be maximized, however, then full-tree or tree-length logging in summer, with maximum dispersal of the skidding pattern, should be prescribed. If cleanliness of site is a major objective, full-tree logging would be prescribed together with a qualification that logging must be suspended during weather cold enough to cause tops and branches to become brittle; Benzie (1971) reported that *most* of the branches on black spruce (*Picea mariana* [Mill.] B.S.P.) in a full-tree logging operation were broken off during skidding when temperatures ranged between -29°C and -34°C. If it is important to avoid damaging bark of residual trees, e.g., seed trees, the prescription could require harvesting operations to be suspended during the "bark slipping" period (DeVries 1971). In other words, the prescription must specifically address every point of consequence.

DECISION-MAKING FOR SILVICULTURAL PRESCRIPTIONS

Pitfalls lie in wait for the prescriber who misses an essential piece of information about a major constraint or interaction. Information overlooked may hold the key to increased efficiency and/or effectiveness of the formulated prescription. What may often stand in the way of avoiding such problems is the sheer quantity of relevant and potentially relevant information available. The abstraction in usable form of relevant material from published sources and the tapping of unpublished experience-based knowledge are recognized as the information management problem in forestry (Schmoldt 1984). Help may be at hand -- in due course (cf. Amarel 1981, Schmoldt 1984). Where "subjective judgement and uncertain information are the cornerstones of decision-making, [rule-based inference] systems fill a void" (Schmoldt 1984). The following account of such systems is drawn mainly from the paper presented by Daniel Schmoldt at the U.S. Midwest Forest Mensurationists Meeting in 1984.

Rule-based inference systems have already proved useful within limited domains in medicine (e.g., for diagnosing bacterial infections, pulmonary diseases, and problems of internal medicine) and geology (for selecting sites for mineral exploration).

In rule-based inference systems, problems are solved and courses of action decided by reference to decision rules applied to the particular problem. Hypotheses are tested against collected evidence and the results are used either for making a decision or as additional evidence for the testing of other hypotheses.

These systems have three main components: (i) a data base containing information specific to the problem under consideration; (ii) a knowledge base, i.e., a set of rules constituting the scientific knowledge and expertise; and (iii) algorithms to manipulate (i) and (ii).

These rules examine the data base and perform various operations, e.g., aggregation, supplementing the data base, and making observations about items in the data base. The form of these decision rules can be described as situation/action pairs, i.e., if particular situations are found to have occurred in the problem under consideration, then the associated action is performed.

The use of rules to express knowledge has the advantage of modularity. Each rule represents a piece of domain-specific knowledge (Duda and Gaschnig 1981) that can be modified readily as the knowledge base improves. The controller/interpreter "navigates through the knowledge base and interprets the rules by examining the situation and performing the required actions".

The rule-based inference system can operate in either of two modes: knowledge acquisition or consultation (Barr and Feigenbaum 1981). In the knowledge acquisition mode, the system interacts with an expert to modify the knowledge base by inserting, deleting, or changing rules. In the consultation mode, the system interacts with a user to provide expertise in the solution of specific problems.

An inference system for silvicultural decision-making would consider the current state of the stand along with management objectives, the landowner's economic situation, various tax incentives, and local forest product markets. The output decisions might be a long-term silvicultural prescription for the life of the stand or a five- or ten-year recommendation for treatment.

Schmoldt (1984) has also noted that these inference systems provide technology transfer, link the researcher and operations personnel, draw on long-term experience (although Brunig's (1984) caution that "experience is not knowledge" should be borne in mind), and allow for continuity over long periods for testing and modifying approaches to forestry decision making.

"Expert systems should be designed not for perfection, with hard and fast decisions, but for improvement and consultation. In this way they become vehicles for adaptive management and for using experience effectively," the very thing for formulators of silvicultural prescriptions!

SUMMARY AND CONCLUSIONS

A silvicultural prescription is a schedule of specific silvicultural measures intended to achieve defined management objectives on a given site. The biological soundness of silvicultural prescription hinges on three elements: the inherent reasonableness of the objectives of management; successful identification of constraints likely to interfere significantly with the attainment of the objectives; and the formulation of a schedule of silvicultural measures that normally will effectively and efficiently reduce constraints sufficiently to secure the objectives. Examples of constraints (one from each of atmospheric, edaphic, and biotic classes) illustrate the kinds of considerations important in prescription formulation. Each example is discussed under biological effects, controlling factors, and prescriptive amelioration. Rule-based inference systems, with expert (self-improving) interpretation of data and knowledge bases, offer good prospects for helping the formulator of silvicultural prescriptions to maximize the usefulness of subjective judgment and of hard and soft information.

LITERATURE CITED

Adams, W.R. 1934. Studies in tolerance of New England trees. XI. The influence of soil temperature on the germination and development of white pine seedlings. Vermont Agriculture Experiment Station, Bulletin 379, 18 p.

Alexander, R.R. 1964. Minimizing windfall around clear cuttings in spruce-fir forests. **Forest Science** 10:130-142.

Alm, A.A. 1971. Site disturbance resulting from mechanized logging and the effect on coniferous reproduction. p. 16-21 *in* Z.A. Zasada, *Ed.* Proc. Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. University of Minnesota, College of Forestry, Forestry Series 11, Agriculture Experiment Station Miscellaneous Report 116.

Amarel, S. 1981. Review of characteristics of current expert systems. Rutgers University, Laboratory of Computer Science Research, Technical Report CBM-TM-89, 9 p.

Atkinson, H.B. and Bay, C.E. 1940. Some factors affecting frost penetration. American Geophysical Union, Transactions Part 3:935-947

Bange, G.G.J. 1953. On the quantitative explanation of stomatal transpiration. **Acta Botanica Neerlandica** 2:255-296.

Barr, A. and Feigenbaum, E.A. 1981. The Handbook of Artificial Intelligence, Volume 1. Kaufmann, Los Altos, California, 409 p.

Benzie, J.W. 1971. Silvicultural interpretations of mechanized harvesting research results (for partial cuttings and multiple use). p. 26-27 *in* Z.A. Zasada, *Ed.* Proc. Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. University of Minnessota, College of Forestry, Forestry Series 11, Agricultural Experiment Station, Miscellaneous Report 116.

Bidwell, R.G.S. 1979. Plant Physiology, 2nd ed. Macmillan, New York. 726 p.

Brunig, E.F. 1984. Designing ecologically stable plantations. p. 348-359 *in* K.F. Wiersum, *Ed.* Strategies and Designs for Afforestation, Reforestation and Tree Planting. Pudoc, Wageningen, The Netherlands.

Buckman, H.O. and Brady, N.C. 1969. The Nature and Properties of Soils, 7th ed. Macmillan, New York. 653 p.

Buss, M. 1980. Research methods applied to the elaboration of stand establishment operations in the Latvian SSR. p. 230-236 *in* Symposium on Stand Establishment Technique and Technology, Proceedings Part I. IUFRO Subject Group S3.02-00.

Chirkov, Y.I. 1979. Soil climate. p. 131-138 *in* J. Seemann, Y.I. Chirkov, J. Lomas, and B. Primault, *Ed.* Agrometeorology. Springer-Verlag, Berlin and New York.

Cochran, P.H. 1969. Thermal properties and surface temperatures of seedbed: a guide for foresters. United States Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Miscellaneous Publication, 19 p.

Cooper, A.J. 1973. Root temperature and plant growth: A review. Commonwealth Bureau of Horticulture and Plantation Crops, Research Review 4, 74 p.

Crabb, G.A. and Smith, J.L. 1953. Soil temperature comparisons under varying covers. National Research Council, Ottawa, Highway Research Board, Bulletin 71:32-80.

Crawford, C.B. 1953. Discussion. p. 48-49 **after** Crabb and Smith 1953.

Decker, W.L. 1985. p. 584-604 *in* D.D. Houghton, *Ed.*, Handbook of Applied Meteorology. Wiley-Interscience, New York.

de Vries, D.A. 1966. Thermal properties in soils. p. 210-235 *in* W.R. van Wijk, *Ed.*, Physics of Plant Environment, 2nd ed. North-Holland, Amsterdam.

DeVries, H.R. 1971. Plantation pine management and mechanization. p. 39-41 *in* Z.A. Zasada, *Ed.* Proc. Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. University of Minnesota, College of Forestry, Forestry Series 11, Agricultural Experiment Station, Miscellaneous Report 116.

Döring, B. 1935. Die Temperatureabhangigkeit der Wasseraufnahme und ihre okologische Bedeutung. **Zeitschrift Botanik** 28:305-383.

Duda, R.O. and Gaschnig, G. 1981. Knowledge-based expert systems come of age. **Byte** 6:239-249.

Fitter, A.H. and Hay, R.K.M. 1981. Environmental Physiology of Plants. Academic Press, London, 355 p.

Ford-Robertson, F.C., *Ed.* 1971. Terminology of Forest Science, Technology Practice and Products. English Language Version. Society of American Foresters, Washington, D.C., 349 p.

Fox, D.G. 1985. Forestry. p. 605-666 *in* D.D. Houghton, *Ed.*, Handbook of Applied Meteorology. Wiley-Interscience, New York.

Gates, D.M. 1965. Radiant energy, its receipt and disposal. **Meteorological Monographs** 6:1-26.

Gates, D.M. 1976. Energy exchange and transpiration. p. 137-147 *in* O.L. Lange, L. Kappan, and E-D. Schulze, *Ed.* Water and Plant Life. Springer-Verlag, Berlin, Ecological Studies No. 19.

Geiger, R. 1950. The Climate Near the Ground. [**Transl**. Das Klima der Bodennahen Luftschicht, 2nd ed. Stewart, M.N. et al.]. Harvard University Press, Cambridge, Massachusetts, 482 p.

Heidmann, L.J. 1976. Frost heaving of tree seedlings: a literature review of abuses and possible control. United States Department of Agriculture, Forest Service, General Technical Report RM-21, 10 p.

Hendrickson, O., Robinson, J.B., and Chatarpaul, L. 1982. The microbiology of forest soils: a literature review. Department of the Environment, Canadian Forestry Service, Chalk River, Ontario, Information Report PI-X-19, 75 p.

Hendrickson, O.Q., Chatarpaul, L., and Robinson, J.B. 1985. Effect of two methods of timber harvesting on microbial processes in forest soils. **Soil Science Society of America Journal** 49:739-746.

Houghton, D.D., *Ed.* 1985. Handbook of Applied Meteorology. Wiley-Interscience, New York, 1461 p.

Jenny, H. 1980. The Soil Resource: Origin and Behavior. Springer-Verlag, New York, 377 p.

Kay, B.D., Grant, C.D., and Groenvelt, P.H. 1985. Significance of ground freezing on soil bulk density under zero tillage. **Soil Science Society of America Journal** 49:973-978.

Keen, B.A. 1932. Soil physics in relation to meteorology. **Quarterly Journal, Royal Meteorological Society** 58:229-250.

Knoll, H.A., Brady, N.C., and Lathwell, D.J. 1964. Effect of soil temperature and phosphorus fertilization on the growth and phosphorus content of corn. **Agronomy Journal** 56:145-147.

Kramer, P.J. 1940. Root resistance as a cause of decreased water absorption by plants at low temperatures. **Plant Physiology** 15:63-79.

Kramer, P.J. 1942. Species differences with respect to water absorption at low soil temperatures. **American Journal of Botany** 29:828-832.

Levitt, J. 1980. Response of Plants to Environmental Stresses, 2nd ed. Vol. I. Chilling, Freezing and High Temperature Stresses. Academic Press, New York, 497 p.

Li, T-T. 1926. Soil temperature as influenced by forest cover. Yale University, School of Forestry Bulletin 18, 92 p.

Liebig, J. 1843. Chemistry in its Applications to Agriculture and Physiology. 3rd ed. L. Playfair, *Ed.*, Taylor and Walton, London, 400 p.

Loucks, O.L. 1966. Topographic exposure as a factor in classifying the productivity of forest land from aerial photographs. **Ecological Society of America Bulletin** 47:106.

Mitscherlich, E.A. 1909. Das Gesetz des Minimums und das Gesetz des abnehmenden Bodenertrages. **Landwirtschaftliches Jahrbuch der Schweiz** 38:537-552.

Mitscherlich, E.A. 1928. Die zweite Annaherung des Wirkungegesetzes der Wachstumsfaktoren. Zeitschrift für Pflanzenernährung und Düngung Bodenkunde A 12:273-281.

Mullin, R. E. 1974. Effects of root exposure on establishment and growth of outplanted trees. p. 229-242 *in* Proc., International Symposium on Ecology and Physiology of Root Growth. Akademie-Verlag, Berlin.

Odin, H. 1979a. Impact of environmental factors on forest development. p. 1-21 *in* Proc., Symposium on Forest Meteorology. World Meteorological Organization, Geneva.

Odin, H. 1979b. Meteorology in forest operations. p. 167-177 *in* Proc., Symposium on Forest Meteorology. World Meteorological Organization, Geneva.

Orlov, A.J. 1957. Nablyudeniya nad sosushchimi Kornyami eli (*Picea excelsa* Link) v estestvennykh usloviyakh. [Observations on absorbing roots of spruce (*Picea excelsa* Link) in natural conditions]. **Botanicheskiy zhurnal** 42:1171-1181. United Department of Commerce, Office of Technical Services, Translocation 60-21109, 15 p.

Oxford English Dictionary. 1971. Compact edition. Oxford University Press, London, 4116 p.

Portz, H.L. 1967. Frost heaving of soil and plants. I. Incidence of frost heaving of forage plants and meteorological relationships. **Agronomy Journal** 59:341-344.

Potter, K.N., Cruse, R.M., and Horton, R. 1985. Tillage effects on soil thermal properties. **Soil Science Society of America Journal** 49:968-973.

Radke, J.K. 1982. Managing early season soil temperatures in the northern Corn Belt using configured soil surfaces and mulches. **Soil Science Society of America Journal** 46:1067-1071.

Richards, S.J., Hagan, R.M., and McCalla, T.M. 1952. Soil temperature and plant growth. p. 303-480 *in* B.T. Shaw, *Ed.* Soil Physical Conditions and Plant Growth. Academic Press, New York.

Ruokonen, M. 1984. Forestry and Forest Products Vocabulary. Commonwealth of Agriculture Bureau, Farnham Royal, Slough, Buckinghamshire, England, 459 p.

Schmoldt, D. 1984. Rule-based inference systems and their applications to forestry. Paper presented at Midwest Forest Mensurationists Meeting, Mackinac Island, Michigan, Sept. 1984 15 p., illus.

Schramm, J.R. 1958. The mechanism of frost heaving of tree seedlings. Proceedings, American Philosophical Society, Philadelphia. 102:333-350.

Sepaskhah, A.R. and Boersma, L. 1979. Thermal conductivity of soils as a function of temperature and water content. **Soil Science Society of America Journal** 43:439-444.

Shul'gin, A.M. 1965. The temperature regime of soils. [Transl. from Russian] United States Department of Commerce, Office Technical Services, Translocation TT-65-50083. Cited by Voorhees et al. 1981, orig. not seen.

Spurr, S.H. and Barnes, B.V. 1980. Forest Ecology, 3rd ed. Wiley and Sons, New York, 687 p.

Sutton, R. F. 1967. Influence of planting depth on early growth of conifers. **Commonwealth Forestry Review** 46:282-295.

Sutton, R.F. 1968. Ecology of young white spruce (*Picea glauca* [Moench] Voss). Cornell University, Ph.D. thesis, University Microfilms, Ann Arbor, Michigan, 68-11645, 500 p.

Sutton, R.F. 1969. Form and development of conifer root systems. Commonwealth Forestry Bureau, Technical Communication 7, 131 p.

Sutton, R.F. and Tinus, R.W. 1983. Root and root system terminology. **Forest Science Monograph** 24, 137 p.

Tamm, O. 1950. Northern Coniferous Forest Soils. [Transl. from Swedish, M.L. Anderson] Scrivener Press, Oxford, 253 p.

Tappeiner, J.C. 1971. Effect of harvesting methods on the distribution of nutrients in slash and litter. p. 13-15 *in* Z.A. Zasada, *Ed.* Proceedings of Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. University of Minnesota, College of Forestry, Forestry Series 11, Agriculture Experimental Station, Miscellaneous Report 116.

Vaartaja, O. 1954. Temperature and evaporation at and near ground level on certain forest sites. **Canadian Journal of Botany** 32:760-783.

van Wijk, W.R. 1966. General temperature variations in a homogeneous soil. p. 144-170 *in* W.R. van Wijk, *Ed.* Physics of Plant Environment, 2nd ed. Wiley and Sons, New York.

van Wijk, W.R. and Borghorst, A.J.W. 1966. Turbulent transfer in air. p. 236-276 *in* W.R. van Wijk, *Ed.* Physics of Plant Environment, 2nd ed. Wiley and Sons, New York.

van Wijk, W.R. and Derksen, W.J. 1966. Sinusoidal temperature variation in a layered soil. p. 171-209 *in* W.R. van Wijk, *Ed.* Physics of Plant Environment, 2nd ed. Wiley and Sons, New York.

van Wijk, W.R. and de Vries, D.A. 1966. Periodic temperature variations in a homogeneous soil. p. 102-143 *in* W.R. van Wijk, *Ed.* Physics of Plant Environment, 2nd ed. Wiley and Sons, New York.

van Wijk, W.R. and Scholte-Ubing, D.W. 1966. Radiation. p. 62-101 *in* W.R. van Wijk, *Ed.* Physics of Plant Environment, 2nd ed. Wiley and Sons, New York.

Voorhees, W.B., Allmaras, R.R., and Johnson, C.E. 1981. Alleviating temperature stress. p. 217-266 *in* G.F. Arkin and H.M. Taylor, *Ed.* Modifying the Root Environment to Reduce Crop Stress. American Society of Agricultural Engineering, St. Joseph, Michigan, ASAE Monograph 4.

Wadsworth, R.M. 1959. An optimum wind speed for plant growth. **Annals of Botany** 23:195-199.

Zasada, Z.A., *Ed.* 1971a. Proceedings of a Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. University of Minnesota, College of Forestry, Forestry Series 11, Agriculture Experimental Station, Miscellaneous Report 116, 51 p.

Zasada, Z.A. 1971b. Silvicultural interpretation of research results for clear cut areas. p. 23-25 *in* Z.A. Zasada, *Ed.* Proceedings of Conference on Biological and Economic Considerations in Mechanized Timber Harvesting. University of Minnesota, College of Forestry, Forestry Series 11, Agricultural Experiment Station, Miscellaneous Report 116.

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BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION AND ITS APPLICATION TO SILVICULTURAL DECISION-MAKING IN BRITISH COLUMBIA

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KEYWORDS: ecosystem classification, silvicultural prescription, pre-harvest silvicultural prescription, hygrotope, trophotope, British Columbia

INTRODUCTION

Ecological classification has been undertaken in British Columbia since the early 1900s; however, it was not until the 1970s that forest managers became interested in its practical application. By then, foresters were expressing increasing concern over reforestation problems, which were often associated with choice of tree species and prescribed burning practices on certain forest sites. It became evident that forestry practices could be markedly improved by basing silvicultural decisions on the ecosystem (site)-specific approach.

In 1975, the British Columbia (B.C.) Ministry of Forests, the agency responsible for managing the 43 million ha of publicly owned productive forest land in the province, initiated a province-wide program of ecosystem classification and interpretation. The objectives of the program were: (i) to characterize and describe the major forest and range ecosystems within B.C.; (ii) to develop management interpretations for the recognized ecosystems; and (iii) to provide forest practitioners with tools for applying the information on an operational basis (Pojar 1983). The biogeoclimatic ecosystem classification developed by Krajina and his students (Krajina 1960, 1969, 1972, 1973; Kojima 1971; Klinka 1976) was adopted and subsequently modified by the Ministry of Forests to meet these objectives. The hierarchical taxonomic system attempts to integrate several components of the ecosystem, including climate, vegetation, soil, and physiography. The

interrelationship of these components provides the conceptual basis for evaluating vegetation-environment patterns and dynamics, and for distinguishing taxonomic units. These units provide a framework for a range of forestry interpretations.

This paper explains the main features of the biogeoclimatic ecosystem classification and describes how it is applied to silvicultural decision-making.

BIOGEOCLIMATIC ECOSYSTEM CLASSIFICATION

The approach

The purpose of the biogeoclimatic ecosystem classification (BEC) system is to organize the complex mosaic of ecosystems observed in the landscape in a way that reveals vegetation-environment relationships and ecosystem function. As the basic unit of classification, an ecosystem represents a geographic area characterized by a particular plant community and its associated site. Though sometimes abrupt, ecosystem boundaries are commonly indistinct, and this introduces some variation into the biotic and abiotic characteristics. Although it encompasses all environmental factors influencing vegetation, site can be conceptually simplified into three elements: climate, hygrotope (soil moisture regime), and trophotope (soil nutrient regime). These features most strongly influence the biotic potential of a site.

The most visible feature of an ecosystem is its vegetation cover. Vegetation has been considered a "phytometer" that reflects the integrated influence of all environmental factors, biotic factors, and past history. Hence, recognition of patterns of vegetation (e.g., plant communities) is essential in understanding the nature and distribution of ecosystems. The BEC system organizes this information at the **vegetation level**. Vegetation is dynamic; it undergoes progressive development through succession and modification with disturbance. To determine vegetation development on a site we require a relatively stable reference point. Initial emphasis is therefore placed on climax or near-climax plant communities as benchmarks for classification as they are more or less at equilibrium with the site and reflect its natural potential. Seral plant communities are incorporated into the classification by showing their site-specific chrono-sequences and their connection with a particular climax community.

Vegetation units based on climax or near-climax stages are not necessarily uniform in environmental properties. Although ecosystems belonging to a particular unit reflect a similar, integrated influence of environmental factors, compensating effects may play an important role. For example, a site with shallow, coarse-textured soil on upper slopes in a wetter climate may support a plant community similar to one occupying a site with deep loamy soil on gentle slopes in a drier climate. There is a need to establish a framework that recognizes different regional climates, enabling us to consider vegetation within more environmentally uniform contexts. This is accomplished by the **climatic level** of classification in the BEC.

Ideally, climatic classification should be based on an adequate meteorological data base and a sound understanding of the critical climatic parameters that distinguish ecologically meaningful classes. Neither data nor understanding are yet sufficient for this purpose. Therefore, climax or near-climax vegetation occurring on "zonal" sites is used to classify and map areas influenced by similar regional climate. Zonal sites generally occur on gentle-to-moderate slopes, in middle-to-upper (in subdued terrain) slope positions, with moderately deep to deep loam soils. The effect of regional climate on vegetation, soil, and other ecosystem components is most strongly expressed in these conditions.

To reduce the complexities associated with successional variation, we require a means of identifying sites regardless of current vegetative cover. This is provided by the **site level** of classification in the BEC. Ecosystems that are environmentally similar to one another and may be considered ecologically equivalent (Bakuzis 1969) form classes at this level. These classes are derived from climax or near-climax plant communities that reflect ecological equivalence. Site-level units are defined by climate, hygrotope, and trophotope, although special environment factors such as duration of snow, duration and frequency of flooding, or windiness, may be used as accessory characteristics for more precise definition. Site-level units represent relatively stable segments of landscape with characteristic biotic potential. They facilitate successional studies by providing a means of linking seral ecosystems into site-specific chronosequences. They also form the basis for deriving forestry interpretations.

The BEC system

The BEC system is built on the vegetation, climate (zonal), and site levels of classification, each of which features a hierarchy of categories (Fig. 1). Taxonomic units from each level are commonly referred to as vegetation units, biogeoclimatic units, and site units, respectively. The principal categories at each level (e.g., plant association, biogeoclimatic subzone, and site association) link the three levels together. For example, zonal plant associations are used to form biogeoclimatic subzones, while all climax plant associations and biogeoclimatic subzones (or variants) are used to derive site associations. This emphasis on interrelationships among classification levels is unique to this system.

Multi-factor, integrated classifications, such as the BEC, are most useful for application to practical forestry (Mueller-Dombois and Ellenberg 1974). Component classifications that develop independent hierarchical classifications for each ecosystem element (soils, vegetation, landform, climate) and subsequently integrate them are less effective in deriving forestry interpretations and more time consuming and costly to apply (Barnes et al. 1982).

The multi-factor, integrated approach to classification has been widely used in Europe (e.g., Dansereau 1957, Jahn 1982) and regionally in the United States by some workers, including Barnes et al. (1982) and Henderson and Peter (1982). In North America, the closest analogues to the BEC system are the site classification system (integrated) of Ontario (Hills 1952, 1976; Jones et al. 1983) and the habitat type system (essentially component) of the western United States (Daubenmire 1968, Pfister and Arno 1980). However, in comparison with the biogeoclimatic system, the forest site system places more emphasis on landform and soil, whereas the habitat type system relies mostly on vegetation. A more detailed description of the biogeoclimatic ecosystem classification can be found in Pojar et al. (1987).

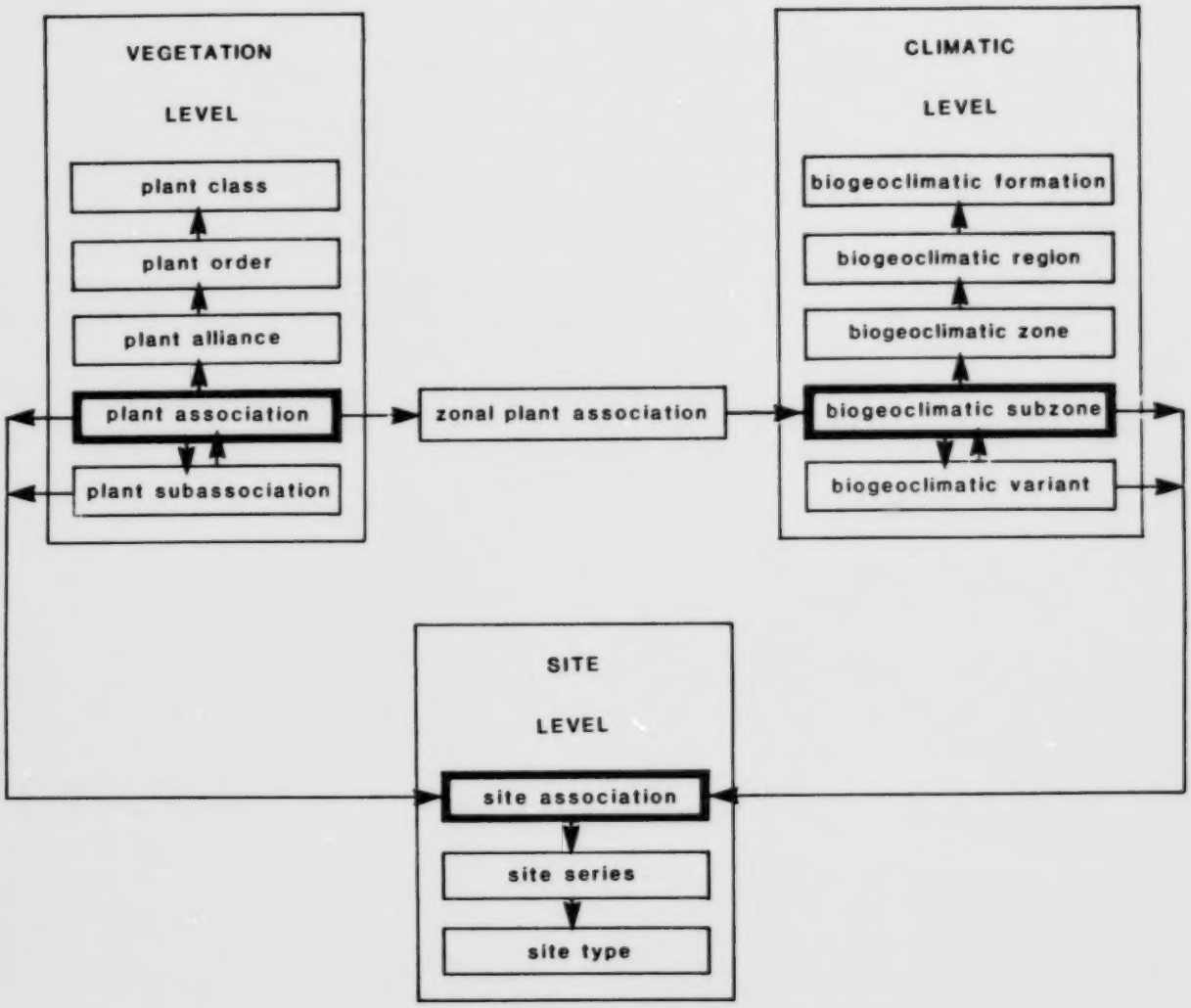


Figure 1. Levels and categories of the biogeoclimatic ecosystem classification (from Pojar et al. 1987)

Site Identification

The BEC system yields a large number of units with detailed floristic and environmental diagnostic characteristics. To be useful to a forester, the results of the classification must be presented in a clear, easy-to-use manner. The identification of component sites comprising an area to be treated is the most important step in applying any interpretations provided by the system. The general approach adopted is to provide users with descriptions of characteristic understorey vegetation and environmental features of units or groups of units from the site level of classification. Aids for users include maps, keys, descriptive tables, slope position diagrams, edatopic grids, and plant identification guides.

As an example, Klinka et al. (1984) used a field-based procedure termed site diagnosis. The objective of this procedure is to evaluate climate, hygrotope, and trophotope, the three elements used to characterize forest sites. The climate is inferred through identification of the biogeoclimatic unit in which the site is located. Maps showing the distribution of biogeoclimatic units at a scale of 1:500,000 are available. Initial identification can be confirmed in the field by using characteristic floristic features of zonal ecosystems described for the biogeoclimatic units.

Hygrotope and trophotope are determined through analysis of both environmental and vegetational features. Several environmental properties that can be assessed relatively easily by field staff form the basis of keys for identifying hygrotope and trophotope (Fig. 2). An edatopic grid is used to portray site units in relationship to hygrotope and trophotope (Fig. 3), with separate grids for different biogeoclimatic units. Vegetation analysis uses indicator species groups as a further means of identifying sites. Eighteen indicator species groups are recognized. Each contains a number of species with similar ranges in hygrotope and trophotope. To identify the site, major indicator species groups represented by plants found on the site are matched with characteristic indicator species groups shown for site units displayed on the edatopic grid. Although both environmental properties and vegetation are analyzed, where vegetation is poorly developed or altered through disturbance, emphasis is placed on the environmental analysis.

INTERPRETATION OF ECOSYSTEMS

The establishment of well stocked stands of desirable tree species fully utilizing the production potential of the sites is the objective of forest managers around the world. Achievement of this goal depends largely on the ability of managers to select the appropriate treatment(s) for each of many different forest ecosystems. The BEC system provides a framework for recognizing ecosystems and presenting interpretations that suggest suitable treatments.

Interpretations for a variety of purposes have been developed on the basis of ecosystem studies and the experience of foresters. Silvicultural interpretations, including choice of tree species, site preparation, regeneration method, and standards for stocking, have all been related

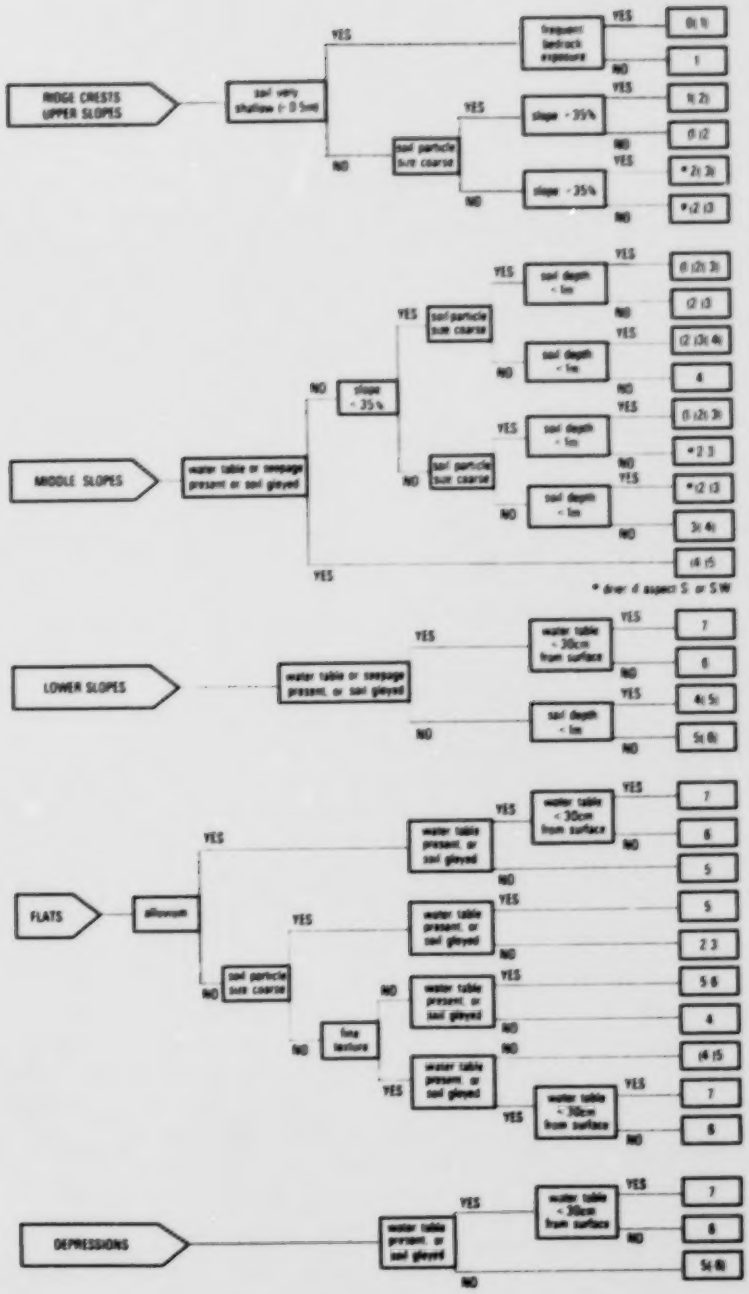


Figure 2. Key to the identification of potential hygrotopes (from Green et al. 1984)

to site units. Biogeoclimatic units have been used as a framework for seed collection and transfer, and seed orchard establishment. Though not yet developed, ecosystem-specific guides to fertilization and thinning are expected.

Two major approaches have been used by the Ministry of Forests to transfer interpretive information to users: i) multiple interpretations for a taxonomic unit (usually site series), and ii) single interpretations for groupings of related taxonomic units. For example, Mitchell and Green (1981), Haeussler et al. (1984), Meidinger et al. (1984), and Pojar et al. (1984) have provided interpretations for individual site series that are identified in the field with climax or near-climax vegetation, slope position diagrams, and other site features such as hygrotope and trophotope. Klinka et al. (1984) recommended tree species by grouping similar site series into interpretive classes that are identified by means of the site diagnosis procedure described previously. Two important interpretations, choice of tree species and prescribed burning, are now described according to the approach of Klinka et al. (1984).

Choice of tree species

Selecting the most appropriate tree species for reforesting a site is one of the most critical decisions in forest management. The outcome of the decision has far-reaching impacts on management and the value of the forest. The principles used in developing the interpretations for tree species selection involve matching ecologically suitable choices of species with management objectives. Ecological characteristics of trees and forest sites are evaluated to determine which tree species are best suited to each site. Those species that meet the management requirements of timber production in accordance with a sustained yield strategy based on site carrying-capacity are submitted to three final selection criteria: maximum sustainable productivity, crop reliability, and silvicultural feasibility. The first criterion implies that the most productive tree species should be selected; the second implies that the species most resistant to damage over the rotation should be selected; the third implies that the selected species should facilitate adoption of the biologically and cost-effective silvicultural system appropriate to the objectives of management. Mixed stands of species compatible in shade tolerance and nutritional requirements are promoted wherever possible to make the best use of the growing space and improve stand resilience (Klinka and Feller 1984).

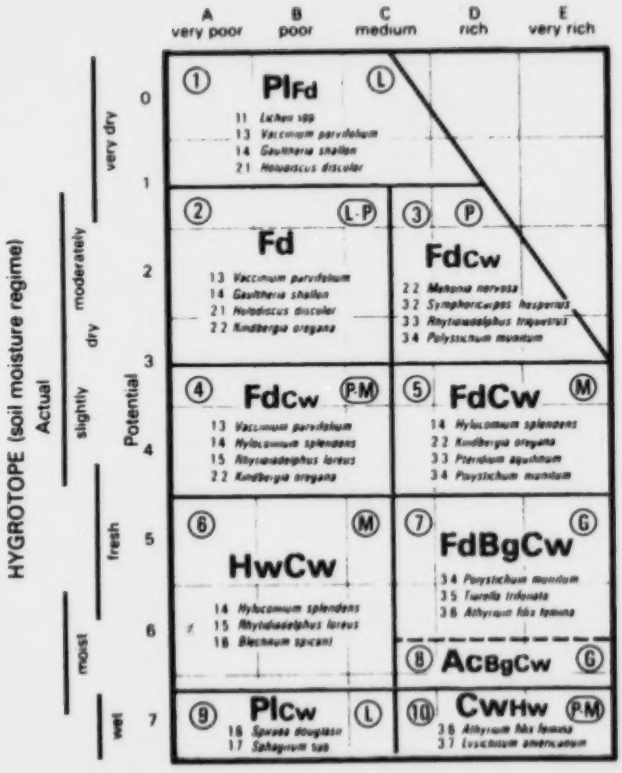
On the basis of these principles, the most appropriate species for the range of sites to be regenerated are selected and presented in the edatopic grid format (Fig. 3). The site units displayed on the grid with bold lines represent groupings of closely related site series which: i) can support stands of the same species composition and structure, ii) have similar productivity potential, and iii) can be managed by the same silvicultural system. For each site unit (referenced with a number), recommended tree species are listed in order of increasing shade tolerance by means of standardized symbols. The size of the symbol indicates the projected role of the species in a stand at rotation age, with large symbols representing major crop species and small symbols minor crop species. Estimated potential productivity of site units is conveyed by symbols, G = good, M = medium, P = poor, and L = low (British Columbia Ministry of Forests 1981). To provide flexibility, alternative species are suggested in comments presented beside each grid. Recommendations may be amended to accommodate local biological, environmental, and management factors.

Grid No. 7

Recommended tree species for the

CWHa1 | **VANCOUVER ISLAND DRIER MARITIME CWH VARIANT**

TROPHOTOPE (soil nutrient regime)



Comments on the Recommended Tree Species for the Vancouver Island Drier Maritime CWH Variant **(CWHa1) – Grid No. 7.**

General Comments:

-- **Lw** is recommended on a trial basis as a minor species on dry sites

-- where recommended, **Cw** (as a major species) or **Lw** and **Pw** (as minor species) are alternatives to **Fd** on sites affected by laminated root rot

-- **Ss** is susceptible to Sitka spruce weevil

Specific Comments:

Site Unit No.

① marginal sites for timber production

② **Pl** is an alternative to **Fd**. **Lw** is an acceptable minor species. **Cw** can function as a non-crop (nurse) species to suppress a lower shrub layer of salal

③ **Lw** or **Pw** are acceptable minor species

④ **Hw** is an alternative to **Fd** in the wettest part of the variant. **Fd-Hw** mixtures, however, are not recommended – **Fd** should be used as a minor to **Hw** or **Hw** as a minor to **Fd**. Inclusion of **Cw** is desirable to both **Hw** or **Fd**

⑤ **Pw** is an acceptable minor species

⑥ **Fd** is an acceptable minor species

⑦ brush hazard sites, establishment of a mixed-species-stand is desirable

⑧ alluvial floodplains, high brush hazard sites. **Cw** or **Bg-Cw** mixtures may be used as major species

⑨ marginal sites for timber production

⑩ brush hazard sites. **Pw** and **Ss** are acceptable minor species. **Hw** (natural) is an acceptable minor species, depending on the frequency of acid organic mounds on the site

Figure 3. Edatopic grid and accompanying comments used to show recommended tree species (from Green et al. 1984); Pl = *Pinus contorta*, Fd = *Pseudotsuga menziesii*, Cw = *Thuja plicata*, Hw = *Tsuga heterophylla*, Bg = *Abies grandis*, Ac = *Populus trichocarpa*, Lw = *Larix occidentalis*. Ss = *Picea sitchensis*, Pw = *Pinus monticola*.

Prescribed burning

Prescribed burning (slash burning) is a forest management practice commonly used in British Columbia to reduce logging debris and forest floor materials in preparation for planting and to reduce fire hazard and insect and disease problems. If conducted carefully, prescribed burning is an effective and relatively inexpensive tool for meeting management objectives. However, indiscriminate use of prescribed burning, particularly on ecologically sensitive sites, may have significant negative effects on regeneration success and site productivity. Disadvantages are generally related to the destruction of surface organic materials, which may result in increased surface erosion, greater soil moisture losses, greater extremes of soil temperature, and, most importantly, loss of plant nutrients (Klock and Grier 1979). The effects on a given site vary with the climatic conditions preceding, during, and following burning, and the intensity of the burn (Feller 1972).

In light of these concerns, the interpretive framework developed for decision-making about prescribed burning is based on the sensitivity of the site to fire (Fig. 4). This interpretation was derived from the results of a large number of studies, including those by Dyrness (1967), Kimmins and Feller (1976), and Wells et al. (1979). The underlying principles dictate that prescribed burning be conducted on a site-specific basis, that the decision about whether or not to burn consider the impact of fire on regeneration of the selected tree species, and that the long-term impact of fire be one of maintaining site productivity, not degrading it.

To aid in the prediction of the potential impact of fire on different sites, an interpretive classification of site sensitivity to fire was developed. This integrates the ecological characteristics for a given site with the ecological effects of fire. Five sensitivity classes are recognized: very high, high, medium, low, and very low. For each class, characteristic environmental features and potential effects of fire are described. A simple key is used to identify the classes in the field; it is based on selected environmental properties determined during the site diagnosis procedure (Fig. 5). A complementary manual permits the making of site- and area-specific slashburning prescriptions (British Columbia Ministry of Forests 1985). Detailed site, fuel, and weather characteristics are used to plan prescribed burns with a target impact-ranking compatible with the site's sensitivity class. For example, low-impact burns would be prescribed for medium or high sensitivity classes, where conservation of organic materials is important. The prescribed burn predictor developed by the Canadian Forestry Service (Muraro 1975) forms the basis for these prescriptions.

In spite of the flexibility built into this decision-making process, situations occur in which management objectives might take precedence over concerns of long-term site productivity, or uncontrollable factors might result in unplanned effects of fire. In such cases, opportunities are sought to conserve or supplement the reserve of site nutrients through selection of tree species, genotypes, and the use of plants living in symbiosis with N-fixing organisms. This, in conjunction with other aspects of nutrient management such as fertilization, may help overcome the adverse effects of fire.

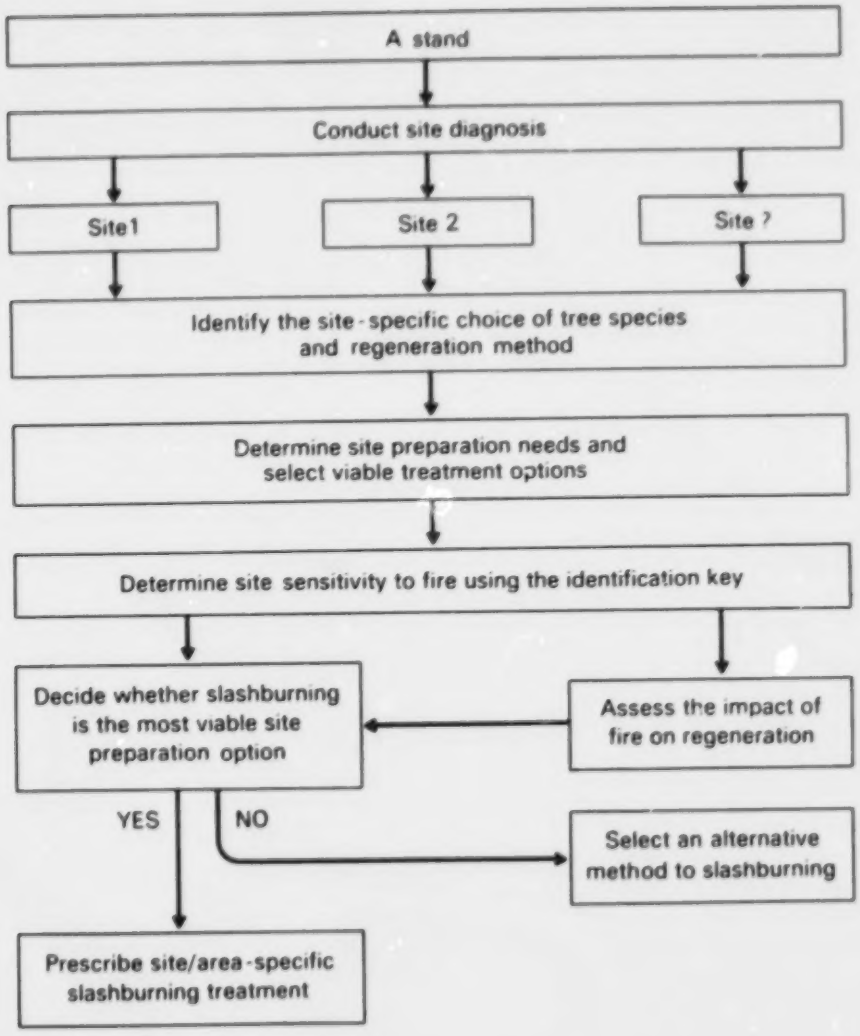

A stand
Conduct site diagnosis
Site1
Site 2
Site ?
Identify the site-specific choice of tree species and regeneration method
Determine site preparation needs and select viable treatment options
Determine site sensitivity to fire using the identification key
Decide whether slashburning is the most viable site preparation option
Assess the impact of fire on regeneration
YES
NO
Select an alternative method to slashburning
Prescribe site/area-specific slashburning treatment

Figure 4. Flow chart illustrating the approach adopted for decision-making about slash burning (from Klinka et al. 1984).

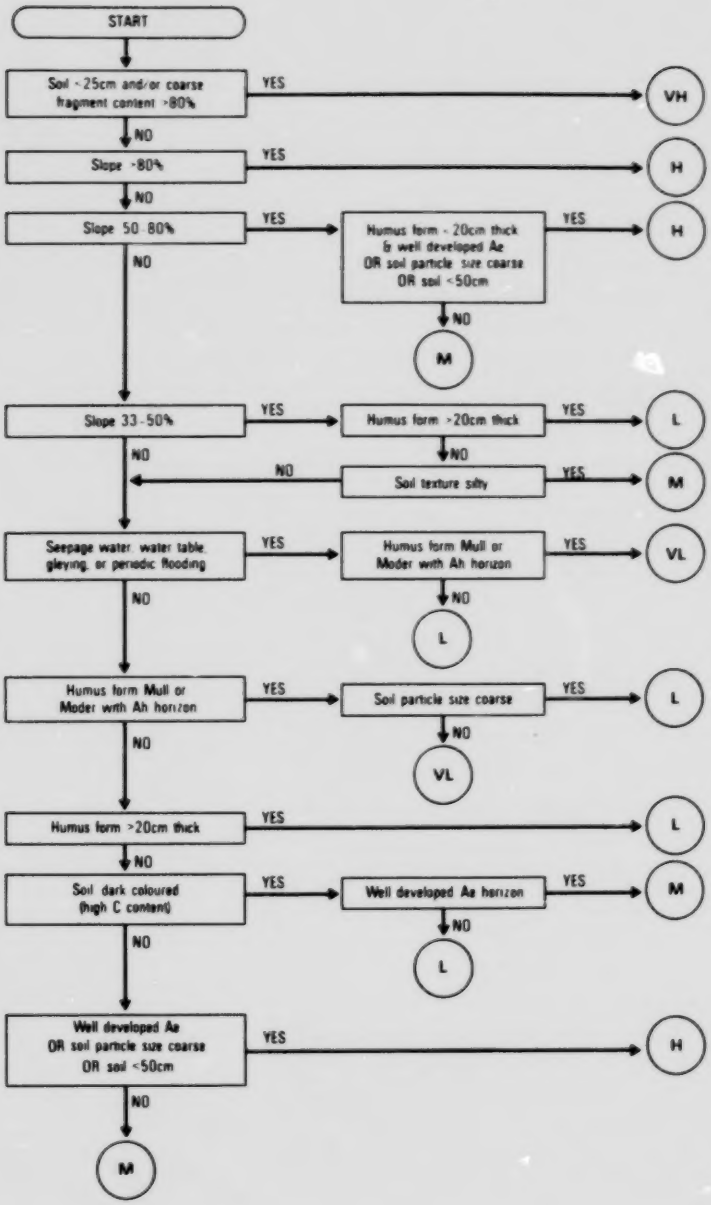


Figure 5. Key to the identification of site sensitivity classes (from Green et al. 1984); VH = very high, H = high, M = medium, L = low, VL = very low.

USE OF THE CLASSIFICATION AND INTERPRETATIONS

Information provided by the BEC is widely used by government and industrial forestry staff as an aid in making day-to-day decisions. Identification of the ecosystems comprising any block proposed for logging or treatment is required for all silvicultural assessments on Crown forest land. The most important effect of all this is in the preharvest silviculture prescription process, whereby all stages from harvesting to established regeneration are prescribed after inspection of areas proposed for logging. The ecological characteristics of the area must be assessed and component sites that differ enough to warrant different treatments must be identified. Thus, proposed treatments are made on a site-specific basis, following the appropriate guidelines. This preharvest prescription policy has been implemented throughout the province. In addition to on-site decision-making, ecosystems comprising larger areas have been mapped in several pilot projects to demonstrate the application of BEC to broader forest management planning (Klinka et al. 1980, Inselberg et al. 1982, Lindeburgh and Trowbridge 1984).

Information is transferred to operational staff through the publication of operational reports, maps, and field guides, together with an intensive training program. Approximately 1200 individuals, from government agencies and forest companies throughout the province, are trained each year. As a result, there has been a dramatic increase in the level of ecological awareness among operational staff. Foresters are now conversant with ecological classification and environment-vegetation relationships, and have a common language to discuss forest ecosystems and their management. This close contact with operational staff also provides an avenue for feedback to validate and fine-tune interpretations.

SUMMARY AND CONCLUSIONS

Biogeoclimatic ecosystem classification is widely used in British Columbia to study and classify forest and range ecosystems, and to aid forest practitioners in making silvicultural prescriptions and management decisions. The system integrates information on vegetation and soils (including physiography) into three levels. At the vegetational level, units are defined by floristic criteria and arranged in a hierarchy; the plant association is the basic unit. The climatic level delineates geographic areas under the influence of similar regional climate by means of (climatic climax) plant associations. Finally, the site level defines environmentally uniform classes representing the sites of climax or near-climax plant associations.

Units derived from the site level form the basis for presenting management interpretations. Two of the important silvicultural decisions to which ecological information is applied are choice of tree species for regeneration and prescribed burning. Field-oriented guides have been developed to assist foresters in making these decisions by using the classification and interpretations. One such guide, for identifying site quality, utilizes environmental and indicator plant

analyses to determine the climate, soil moisture regime, and soil nutrient regime. Sites of similar quality are grouped into site units and displayed on edatopic grids, which show tree species recommendations. Prescribed burning decisions are based on an assessment of site sensitivity to fire in terms of productivity impact. Guides such as these are used throughout British Columbia by government and industry forestry staff; they have substantially improved the ecological soundness of silvicultural prescriptions made.

Application of the BEC over the past 10 years has greatly improved the success of silvicultural prescriptions. For example, where once one tree species was planted over large, ecologically diverse areas, with consequent regeneration failures, species are now matched to site and plantations of mixed species are established. In addition, ecological criteria have been used to extend the range of certain tree species into areas where they outperform local species. As well, severe site degradation from indiscriminate slash-burning is now less common, although the outcome of prescribed burning is influenced by many factors beyond the realm of forest ecology. Furthermore, the results of research and operational trials can be extrapolated to other areas more successfully within the BEC framework. Foresters in British Columbia now have an effective tool for improving their understanding of the ecosystems they manage, for formulating prescriptions, and for predicting the consequences of their decisions. This enables "applied ecology" to be practised.

LITERATURE CITED

Anon. 1981. Site index equations and curves for the major tree species in British Columbia. British Columbia Ministry of Forests, Forest Inventory Branch. Victoria, British Colubmia, Forest Inventory Report 1, 33 p.

Anon. 1985. A guide to prescribed broadcast burning in the Vancouver Forest Region. British Columbia Ministry of Forests, Vancouver Forest Region, Vancouver, B.C., 110 p.

Bakuzis, E.V. 1969. Forestry viewed in an ecosystem perspective. p. 189-258 *in* G.M. Van Dyke, *Ed.* The Ecosystem Concept in Natural Resource Management. Academic Press, New York.

Barnes, B.V., Pregitzer, K.S., Spies, T.A., and Spooner, V.H. 1982. Ecological forest site classification. **Journal of Forestry** 80:493-498.

Dansereau, P. 1957. Biogeography: an ecological perspective. Roland Press, New York, 394 p.

Daubenmire, R. 1968. Plant Communities. Harper and Row, New York, 300 p.

Dyrness, C.T. 1967. Erodibility and erosion potential of forest watersheds. p. 599-611 *in* W.E. Sopper and H.W. Lull, *Ed.* International Symposium on Forest Hydrology. Pergamon Press, Elmsford, New York.

Feller, M.C. 1972. The ecological effects of slashburning with particular reference to British Columbia: a literature review. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 13, 60 p.

Green, R.N., Courtin, P.J., Klinka, K., Slaco, R.J., and Ray, C.A. 1984. Site diagnosis, tree species selection, and slashburning guidelines for the Vancouver Forest Region. Abridged version. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Handbook 8, 143 p.

Haeussler, S., Pojar, J., Geisler, B.M., Yole, D., and Annas, R.M. 1984. A guide to the Coastal Western Hemlock Zone, Northern Drier Maritime Subzone (CWHf) in the Prince Rupert Forest Region, British Columbia. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 21, 163 p.

Henderson, J.A. and Peter, D. 1982. Preliminary plant associations and habitat types of the Soleduck Ranger District, Olympia National Forest, United States Department of Agriculture Forestry Service, Pacific Northwest Region, Portland, Oregon, 81 p.

Hills, G.A. 1952. The classification and evaluation of site for forestry. Ontario Department of Lands and Forests, Toronto, Ontario, Research Report 24, 41 p.

Hills, G.A. 1976. An integrated iterative approach to ecosystem classification. p. 73-97 *in* J. Thie and G. Ironside, *Ed.* Ecological (Biophysical) Land Classification in Canada. Department of the Environment, Lands Directorate, Ottawa, Ontario, Ecological Land Classification Series No. 1.

Inselberg, A.E., Klinka, K., and Ray, C. 1982. Ecosystems of MacMillan Park on Vancouver Island. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 12, 113 p.

Jahn, G. *Ed.* 1982. Application of Vegetation Science to Forestry. Junk, The Hague, The Netherlands, 405 p.

Jones, R.K., Pierpoint, G., Wickware, G.M., Jeglum, J.K., Arnup, R.W., and Bowles, J.M. 1983. Field guide to forest ecosystem classification for the Clay Belt, Site Region 30. Ontario Ministry of Natural Resources, Maple, Ontario, 123 p.

Kimmins, J.P. and Feller, M.C. 1976. Effects of clearcutting and broadcast slashburning on nutrient budgets, streamwater chemistry and productivity in western Canada. p. 186-197 *in* Proceedings Division 1, International Union of Forestry Research Organizations 16th World Congress, Oslo, Norway.

Klinka, K. 1976. Ecosystem units, their classification, interpretation, and mapping in the University of British Columbia Research Forest. University of British Columbia, Faculty of Forestry, Department of Botany and Soil Science, PhD thesis, 622 p.

Klinka, K. and Feller, M.C. 1984. Principles used in selecting tree species for regeneration of forest sites in southwestern British Columbia. **Forestry Chronicle** 60:77-85.

Klinka, K., Green, R.N., Courtin, P.J., and Nuszdorfer, F.C. 1984. Site diagnosis, tree species selection, and slashburning guidelines for the Vancouver Forest Region. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 25, 180 p.

Klinka, K., van der Horst, W.D., Nuszdorfer, F.C., and Harding, R.G. 1980. An ecosystematic approach to a subunit plan. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 5, 118 p.

Klock, G.O. and Grier, C.C. 1979. Effects of fire on the long-term maintenance of forest productivity. p. 247-250 *in* S.P. Gessel, R.M. Kenady and W.A. Atkinson, *Ed.* University of Washington, College of Forest Resources, Seattle.

Kojima, S. 1971. Phytogeocoenoses of the Coastal Western Hemlock Zone in Strathcona Provincial Park, British Columbia, Canada. University of British Columbia, Department of Botany, PhD thesis, 321 p.

Krajina, V.J. 1960. Ecosystem classification of forests. **Silva Fennica** 105:107-110.

Krajina, V.J. 1969. Ecology of forest trees in British Columbia. **Ecology of Western North America** 2:1-146.

Krajina, V.J. 1972. Ecosystem perspectives in forestry. The H. R. MacMillan lectureship in forestry. University of British Columbia, Faculty of Forestry, 31 p.

Krajina, V.J. 1973. Biogeoclimatic zones of British Columbia. British Columbia Department of Lands and Forests and Resources, Ecological Research Communication, 1:1,900,800 colored map.

Lindeburgh, S. and Trowbridge, R. 1984. Production of forestry interpretative maps and management summaries from ecologically-based polygons. British Columbia Ministry of Forests, Victoria, British Columbia, Research Report RR85001-PR, 28 p.

Meidinger, D.V., Hope, G.D., and McLeod, A.J. 1984. Classification and interpretation of some ecosystems of the Rocky Mountain Trench, Prince George Forest Region, British Columbia. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 22, 21 p.

Mitchell, W.R. and Green, R.N. 1981. Identification and interpretation of ecosystems of the western Kamloops Forest Region. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Handbook 2 (2 vol.), not paginated.

Mueller-Dombois, D., and Ellenberg, E. 1974. Aims and Methods of Vegetation Ecology. Wiley and Sons, Toronto, 547 p.

Muraro, S.J. 1975. Prescribed fire predictor. Department of the Environment, Canadian Forestry Service, Victoria, British Columbia.

Pfister, R.D. and Arno, S.F. 1980. Classifying forest habitat types based on potential climax vegetation. **Forest Science** 26:52-70.

Pojar, J., Trowbridge, R., and Coates, D. 1984. Ecosystem classification and interpretation of the Sub-Boreal Spruce Zone, Prince Rupert Forest Region, British Columbia. British Columbia Ministry of Forests, Victoria, British Columbia, Land Management Report 17, 319 p.

Pojar, J. *Ed.* 1983. Forest ecology. p. 221-318 *in* S.B. Watts, *Ed.* Forestry Handbook for British Columbia, 4th ed. Forestry Undergraduate Society, University of British Columbia. Friesen and Sons, Cloverdale, British Columbia.

Pojar, J., Klinka, K., and Meidinger, D. 1987. Biogeoclimatic ecosystem classification in British Columbia. **Forest Ecology and Management** 22:119-154.

Wells, C.G., Campbell, R.E., DeBano, L.F., Lewis, C.E., Fredrikson, R.L., Franklin, E.C., Froelich, R.C., and Dunn, P.H. 1979. Effects of fire on soil: A state-of-knowledge review. United States Department of Agriculture, Forest Service, General Technical Report WO-7, 34 p.

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SCARIFICATION REQUIREMENTS FOR REGENERATING PAPER BIRCH (BETULA PAPYRIFERA) UNDER SHELTERWOOD

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KEYWORDS: seedbeds, mineral soil, coarse woody debris, seedling establishment, site preparation, scarification, shelterwood, *Betula papyrifera*

INTRODUCTION

Clearcutting in blocks, strips, patches, or groups is a widely recommended method of regenerating paper birch (*Betula papyrifera* Marsh.) (Nash 1948, Safford 1983) and the ecologically equivalent white birch (*B. pendula* Roth) and downy birch (*B. pubescens* Erhr.) of northern Europe (Lehonkoski 1940, Sarvas 1948). Clearcuts should be not so large as to exceed the effective seeding range of birch, which varies with size of seed crop. For example, Zasada and Gregory (1972) found in Alaska that seed crops of paper birch were adequate to regenerate a 30-m-wide strip only one year in four.

On larger cutting units, 7-12 birch trees/ha are needed to provide seed (Filip 1969, Marquis et al. 1969, Safford 1983, Safford and Jacobs 1983). Sarvas (1948) recommended leaving 4-8 high-grade, sawlog-size Eurasian white birch seed trees/ha.

The two-cut shelterwood system is highly favored for yellow birch (*Betula alleghaniensis* Britton) (Tubbs et al. 1983), and may be used in some circumstances for paper birch (Safford 1983) and for the Eurasian birches (Sarvas 1948, Hagner 1962). Safford (1983) recommended removing 60% of stand basal area, leaving at least 10-12 paper birch seed trees/ha in the shelterwood. The shelterwood should be removed after 2 years to minimize deterioration of the birch (Nash 1948), and to minimize the establishment of shade-tolerant species.

Single-tree selection systems tend to favor the regeneration of shade-tolerant species, and they are therefore not advocated for regenerating either paper birch or the Eurasian birches.

Paper birch does not regenerate well in even the smallest clearcuts in the north central region of the United States of America (USA) despite the presence of seed trees in adjacent uncut stands. Most of these clearcuts are intended to regenerate aspen (*Populus tremuloides* Michx., *P. grandidentata* Michx.) by root suckers (Perala and Russell 1983), the rapid juvenile growth of which creates a highly competitive environment for paper birch seedlings. Even after site preparation for coniferous planting has exposed favorable mineral-soil seedbeds in clearcuts, paper birch is seldom more than a minor component of the recolonizing vegetation. Most attempts to regenerate paper birch by the seed tree method have also failed.

The lack of success of the clearcut and seed-tree systems in the north central region of the United States may be ascribed to many factors, most notably unreceptive seedbeds that provide hostile microclimates for seedling germination and establishment, uncontrolled competition from vegetation, and inadequate quantity and quality of seed. Climate seems to be the factor that differs most between the north central and the northeastern regions, where paper birch regenerates more readily. Average annual surface-water runoff (an index of water sufficiency) in the northeast ranges from 500 to 1000 mm or more, but only about 125 to 400 mm across northern Minnesota, Wisconsin, and Michigan (Geraghty et al. 1973).

The use of the shelterwood system for regenerating paper birch under the relatively dry conditions that prevail in the north central USA is poorly documented. This paper reports a study of scarification both in controlling competing vegetation and in providing suitable seedbeds for paper birch: it also examines the influence of the shelterwood canopy on birch establishment and growth.

METHODS

Study area

The study is located at the University of Minnesota Cloquet Forestry Centre (46°43' N, 92°29'W), about 32 km southwest of Duluth, Minnesota, USA, in the Spruce-Fir forest section (Bailey 1980). The climate is continental, with warm, humid summers and cold winters. July mean temperature and annual precipitation average 19°C and 685 mm, respectively. The soil is a Cloquet sandy loam (mixed, frigid Typic Dystrochrept). A mature stand (60 years old) primarily of aspen and paper birch dominated the area. The site index for aspen was 17 m at 50 years, and the total stand basal area averaged 19 m²/ha, about 41% aspen and 32% birch. A very dense shrub layer consisted mostly of hazel (*Corylus americana* Walt.), with lesser amounts of bush honeysuckle (*Diervilla lonicera* Mill.) and minor amounts of 14 other species. A lush herb layer (44 species) was dominated by *Aster macrophyllus* L., *Aralia nudicaulis* L., *Pteridium aquilinum* (L.) Kuhn, and some grasses and sedges.

Field

From 2 July to 8 August 1979, eight 1-ha plots were clearcut and a further four 1-ha plots were partially cut to leave a paper birch shelterwood averaging 9.5 m^2/ha basal area and 29% crown cover. Four 1-ha plots were left uncut as controls. Four of the clearcut plots and two of the partially cut plots were full-tree skidded (entire tree above stump) and the other four clearcut and two partially cut plots were tree-length skidded (branches, unmerchantable trees and tops left on site). Four of the clearcut plots were destined for conversion to white spruce (*Picea glauca* [Moench] Voss); four were to be regenerated naturally by aspen suckering. The shelterwoods were intended to regenerate paper birch by natural seeding.

The shelterwood plots were cross-disked with a narrow fire disk during the last week of October 1980. The conversion plots were prepared for planting on 13 May 1981 with a Bräcke[1] patch scarifier to create planting spots spaced about 2.1 x 2.4 m. From 16 to 18 June 1981, white spruce, greenhouse grown in Ray Leach Pine Cells, were planted by hand on the shoulder of the patches.

The shelterwood on one treatment plot was removed in March 1984.

Sampling

Each treatment plot was sampled by means of four permanent 500-m^2 circular tree layer plots (trees > 2.5 cm DBH), eight temporary 4-m^2 circular tall shrub quadrats (trees and shrubs > 15 cm tall, < 2.5 cm DBH), and eight temporary rectangular (1.0- x 0.5-m) quadrats for short shrubs and tree seedlings (< 15 cm tall), and herbs.

Forty permanent 1.0- x 0.5-m seedbed quadrats for detailed assessment of seedbed condition and revegetation were installed systematically along diagonal transects in each shelterwood treatment plot in November 1980.

Tree diameters at breast height (1.37 m) were measured in all treatment plots in June 1977. Diameters of the shelterwood trees were remeasured in January 1983, when vertical crown projection and tree location were also mapped.

Tree seedlings, shrubs, and herbs in all treatment plots were sampled in late July or August in 1977, from 1979 through 1982, and in 1984. Shrubs were recorded by species and diameter at 15-cm stem height. Herbs were recorded by species, clipped by quadrat, and composited to determine above-ground dry weight (70°C oven).

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[1] Mention of trade names is for the reader's convenience and does not constitute endorsement by the United States Department of Agriculture.

From the fall of 1980 to the spring of 1983, 12 to 15 seed traps (1 m^2) were installed in each silvicultural treatment; they were emptied three or four times each fall and once in the spring. During the study period, only the 1981 seed crop was substantial. Seeds collected from the traps were air dried and stored at 4°C; germination tests were conducted in February 1982 at 22°C in the dark. Germination was 12% in 1980 and 41% in 1981. By silvicultural system, the numbers of viable birch seeds per m^2 were: shelterwood 0.4 (1980), 2313 (1981), and none (1982); clearcut 168 (1981); and controls 3159 (1981).

The proportion of each shelterwood seedbed quadrat surface with exposed mineral soil and embedded, coarse, woody debris was estimated by eye in early July 1981. In 1982, shrubs and tree seedlings on these quadrats were recorded by species and diameter (mm) at 15 cm. The total number of birch seedlings was recorded in late summer or fall annually from 1981 through 1984. Birch seedlings were classed by year of origin in 1982 only. The height of the tallest seedling on each seedbed quadrat was recorded annually from 1982 through 1984.

Analysis

The data for all regeneration treatment plots were analyzed by ANOVA with linear contrasts to test significant differences in the number of birch seedlings by years and regeneration treatment ($n=80$). The shelterwood seedbed data were averaged by quarter hectare (10 seedbeds per tree measurement plot with canopy cover estimates) and analyzed independently by year according to multiple linear regression ($n=16$) with the derived model:

$$Y = a + b\,PMS + c\,PWD + d\,(PCC)^2 + e \qquad \text{(eq.1)}$$

where: Y = independent variable (seedlings per m^2 or seedling height),
PMS = percent exposed mineral soil,
PWD = percent of seedbed embedded with coarse, woody debris,
PCC = percent canopy cover,
a, b, c, d = determined coefficients,
e = random error.

Seedling count data were normalized by the transformation $Y = \sqrt{(N + 1)}$, and retransformed for reporting. Significance was declared at the 5% testing level. Other data presented here were not statistically tested.

RESULTS AND DISCUSSION

Five years after logging, the shelterwood system with disk scarification had the highest birch stocking. It produced nearly three times more birch seedlings than the conifer conversion treatment did, 10 times more than the aspen treatment, and 250 times more than the control (Table 1).

Table 1. Frequency, stocking density, and mean stem diameter of paper birch seedlings more than 15 cm tall, by year and regeneration treatment.

Regeneration treatment	Year				
	1977	1980	1981	1982	1984
			frequency, percent[a]		
Birch	0	3	0	50	49
Conifer	0	0	0	13	23
Aspen	0	0	6	16	10
Control	0	0	0	6	1
			stems, n/m^2		
Birch[b]	0	0.38	0	2.94	2.15
Conifer	0	0	0	0.38	0.77
Aspen	0	0	0.31	0.50	0.20
Control	0	0	0	0.19	0.01
			stem diameter, mm		
Birch	0	3	0	4	6
Conifer	0	0	3	3	7
Aspen	0	0	3	3	11
Control	0	0	0	3	9

[a] Percent of 0.5–m^2 plots stocked with at least one paper birch seedling more than 15 cm tall.

[b] Important significant contrasts: birch > (aspen + conifer); aspen = conifer; control < (aspen + birch + conifer); 1982 > 1984.

The number of seedlings peaked in 1982 except for the conifer conversion, which was highest in 1984. Mean stem diameter of the birch seedlings was greatest in the aspen treatment, intermediate in the control and in the conifer conversion, and least in the birch shelterwood (Table 1). This probably reflects variation in the severity of competition among the treatments. Only larger seedlings were able to survive the intense competition in the aspen treatment and the control, whereas the birch shelterwood with scarification allowed many smaller seedlings to survive.

The total number of birch seedlings in the shelterwood was highest in 1982 after the bumper crop of birch seed the previous year (Table 2). Mortality was high; fully two-thirds of the seedlings found in 1982 were dead by 1983, and about 40% of those survivors died within a year.

Seedlings attained a mean dominant height of 64.8 cm after 4 years (Table 2). The dominance of competing shrubs and herbs (as measured by basal area at 15 cm and by biomass, respectively) was greatly reduced by disking; the former attained pre-disking values after three years, the latter after two years (Table 2).

Table 2. Density and mean height of paper birch regeneration, shrub basal area, and above-ground biomass of herbs, after shelterwood cut in 1979 and disking in October 1980.

Item	Units	Year				
		1980	1981	1982	1983	1984
Seedling density	n/m^2	–	4.6	50.5	16.5	9.4
Seedling height	mm	–	–	330	425	648
Shrub basal area	cm^2/m^2	4.8	0.7	2.8	–	6.7
Herb ovendry biomass	g/m^2	116	58	136	–	229

Stocking of birch seedlings after three years improved by nearly one seedling/m^2 for each 2% of mineral soil exposed by disking (Table 3). Percent mineral soil did not, however, affect seedling height growth. Coarse, woody debris also improved birch stocking significantly and, more importantly, seedling growth (Table 3). Seedlings gained more than 1 cm in height increment per 1% increase in coarse, woody debris. For seedling establishment and growth, woody debris, at least in the form of brown cubical decayed wood, is important by virtue of its roles in supplying water and phosphorus, providing inoculum for mycorrhizal development, and fixing atmospheric nitrogen (Larsen et al. 1980).

Table 3. Effect of exposed mineral soil, coarse woody debris, and canopy cover on paper birch seedling density and dominant height in 1983[a].

Independent variable	Density (n/m^2)	Height (mm)
Mineral soil	+21.7*	– 7
Coarse woody debris	+21.9*	+231*
Canopy cover	– 15.3	– 122

[a] Expressed as a change in seedling numbers or height over the range of independent variable values encountered in the study: mineral soil = 49–98%; woody debris = 8–28%; canopy cover = 8–64%. Asterisks indicate statistically significant differences from zero at 5% level.

Both stocking and growth of paper birch seedlings declined exponentially with increasing canopy, but the relationships were not statistically significant (Table 3). Others have shown that seedlings of both paper birch (Logan 1965, Marquis 1966) and the Eurasian birches (Sarvas 1948, Hagner 1962) respond favorably to moderate shade, but are hindered by canopies exceeding 20-40%. Modeled from equation 1, a 25% canopy in this study, in comparison with an 8% canopy, would reduce seedling stocking by less than 15% and height by less than 5%, trivial amounts.

Birch seedlings were fewer by 14% and shorter by 24% after removal of the shelterwood, but the differences were not statistically significant. Both logging and subsequent exposure to full sunlight caused seedling mortality or dieback. Many of the taller seedlings resprouted vigorously.

Although the 1981 bumper seed crop accounted for 94% of all seedlings in 1982, the seedlings established in 1981 account for virtually all the tallest seedlings. Even the most unlikely quirk of sampling could hardly account for the 4.6 birch seedlings/m^2 in 1981 from the 0.4 viable birch seedfall per m^2 in 1980. The only explanation seems to be that birch may accumulate one or more years of seed in a semi-persistent seedbank in the forest floor (cf. Zasada et al. 1977). This was tested by sampling the forest floor in the control plots in September 1982 (one year after the bumper seed crop) and culturing it in flats in a greenhouse. Paper birch germinated there at the rate of 189 seedlings/m^2 of sampled forest floor!

SUMMARY AND CONCLUSIONS

A two-stage shelterwood system appears to be a viable option for regenerating paper birch where summer precipitation is limiting in amount or frequency. The shelterwood should be light (about 25% canopy) to conserve soil moisture by shading, yet not hinder germination, establishment, and growth of seedlings. Seedling survival and height growth are diminished exponentially with increasing canopy. The main value of the shelterwood canopy may be in providing abundant seed, which even in a poor seed year may be sufficient for adequate regeneration. The shelterwood can even be successful in a year without seed, provided that seed from at least one previous good seed year is stored in the forest floor. This "seedbank" concept needs to be investigated further for both shelterwood and clearcut systems. The success of the shelterwood system depends on the availability of seedbeds suitable for seed germination and seedling growth. The ideal seedbed is not easily provided because the treatment that best controls competing vegetation compromises the adequacy of nutrients and water available to birch seedlings. Thorough tilling disrupts vegetation and exposes mineral soil but may bury vital nutrients out of immediate reach of birch germinants. In contrast, the needs of birch seedlings for nutrients are met by minimal tilling that breaks down and incorporates the forest floor, notably coarse, woody debris, into the surface mineral soil to form a nutrient-rich medium with a relatively high moisture-holding capacity. This provides little vegetation control, however. Currently available equipment cannot fully meet this dual requirement, but disks and perhaps disk-trenchers can create reasonable approximations by providing a variety of microsites, some of which approach optimum.

ACKNOWLEDGMENTS

This study was installed with the cooperation of the University of Minnesota. The helpfulness of Professors A.R. Hallgren and A.A. Alm are especially appreciated.

LITERATURE CITED

Bailey, R.G. 1980. Description of the ecoregions of the United States. United States Department of Agriculture, Forest Service, Washington, 77 p. + map.

Filip, S.M. 1969. Natural regeneration of birch in New England. p. 50-54 *in* Birch Symposium Proceedings. United States Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Geraghty, J.J., Miller, D.W., van der Laden, F., and Troise, F.L. 1973. Water atlas of the United States. Water Information Center, Port Washington, New York, unpaginated, 122 plates.

Hagner, S. 1962. Naturdig föryngring under skärm. Meddelanden Frân Statens Skogsforskningsinstitut 52(4):1-263.

Larsen, M.J., Harvey, A.E., and Jurgensen, M.F. 1980. Residue decay processes and associated environmental functions in northern Rocky Mountain forests. p. 157-174 *in* Environmental Consequences of Timber Harvesting in Rocky Mountain Coniferous Forests: Symposium Proceedings. United States Department of Agriculture, Forest Service, General Technical Report INT-90.

Lehonkoski, N.A. 1940. Känner du ditt björkbestând? **Skogen** 27:3-6, 57-59, 77-79.

Logan, K.T. 1965. Growth of tree seedlings as affected by light intensity. I. White birch, yellow birch, sugar maple and silver maple. Canada Department of Forestry, Publication 1121, 16 p.

Marquis, D.A. 1966. Germination and growth of paper birch and yellow birch on simulated strip cuttings. United States Department of Agriculture, Forest Service, Research Paper NE-54, 19 p.

Marquis, D.A., Solomen, D.S., and Bjorkbom, J.C. 1969. A silvicultural guide for paper birch in the Northeast. United States Department of Agriculture, Forest Service, Research Paper NE-130, 47 p.

Nash, R.W. 1948. Studies of birch. p. 107-122 *in* Maine Forestry Communication, Report 27.

Perala, D.A. and Russell, J. 1983. Aspen. p. 113-115 *in* R.M. Burns, **Technical Compiler**. Silvicultural Systems for the Major Forest Types of the United States. United States Department of Agriculture, Forest Service, Agriculture Handbook 445.

Safford, L.O. 1983. Silvicultural guide for paper birch in the Northeast (revised). United States Department of Agriculture, Forest Service, Research Paper NE-535, 29 p.

Safford, L.O. and Jacobs, R.D. 1983. Paper birch. p. 145-147 *in* R.M. Burns, **Technical Compiler**. Silvicultural Systems for the Major Forest Types of the United States. United States Department of Agriculture, Forest Service, Agriculture Handbook 445.

Sarvas, R. 1948. Tutkimuksia doivun uudistumisesta etelä-soumessa. Communicationes Institut Forestalis Fenniae 35(4):1-91.

Tubbs, C.H., Jacobs, R.D., and Cutler, D. 1983. Northern hardwoods. p. 121-127 *in* R.M. Burns, **Technical Compiler**. Silvicultural Systems for the Major Forest Types of the United States. United States Department of Agriculture, Forest Service, Agriculture Handbook 445.

Zasada, J.C. and Gregory, R.A. 1972. Paper birch seed production in the Tanana Valley, Alaska. United States Department of Agriculture, Forest Service, Research Note PNW-177, 7 p.

Zasada, J.C., VanCleve, K., Werner, R.A., McQueen, J.A., and Nyland, E. 1977. Forest biology and management in high-latitude North American forests. p. 137-195 *in* North American Lands at Latitudes North of 60°: Symposium Proceedings. United States Department of Agriculture, Forest Service, Institute of Northern Forestry, Fairbanks, Alaska.

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SILVICULTURAL PRESCRIPTIONS AND STAND ESTABLISHMENT TECHNIQUES FOR PICEA ABIES (L.) KARST. IN RHEINLAND-PFALZ, FEDERAL REPUBLIC OF GERMANY

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INTRODUCTION

In the Federal Republic of Germany, social values of the forest in many instances are becoming more important than economic values, as, for example, in response to the threatening development of acid rain damage to the forest. In recent years, conflict has increasingly crystallized out of two opposing factors: on one hand, increasing mechanization of forestry work and, on the other hand, a steadily growing awareness of nature. In these circumstances, it is difficult for a forester to balance profit with protection and recreation and at the same time ensure effective cultivation of the forest.

The first silvicultural prescriptions were formulated some 140 years ago in order to direct silviculture, the central concern of forest management, into orderly channels without losing sight of economic principles.

Norway Spruce Distribution in Southwest Germany

Norway spruce (*Picea abies* [L.] Karst.) is the predominant tree species in the Federal Republic of Germany, occupying about 40% of the total forest area, twice as much as the next most

common species. It occupies 35% of the forest land in the federal state of Rheinland-Pfalz (Schmidt-Vogt 1977).

As recently as 1800, Norway spruce was not found throughout Rheinland-Pfalz. However, cultivation of spruce, especially in pure stands, has increased greatly over the last 150 years. Cultivation is concentrated on medium- to high-elevation (300-600 m) sites but has spread to lower elevations in the foothills and plains. Today, we consider as ecologically precarious the high proportion of spruce in areas where it is not native. Particularly worrisome are the threats posed by storm and snow.

Acid rain damage: current status

According to a 1984 survey of forest damage in the Federal Republic of Germany (BML 1984) (Table 1), more than 50% of all Norway spruce in Germany and 36% of spruce in Rheinland-Pfalz have been damaged by "acid rain". The number of trees affected increased by some 10% in one year. This suggests that the emission of toxins from cars and industrial plants must be reduced drastically. However, there will also be silvicultural consequences; fertilization may have to be increased greatly, crop species may have to be alternated, and different cultivation concepts may be needed. For this purpose, updated silvicultural prescriptions for spruce are very useful.

Table 1. Damage by tree species

Tree species	Forest area occupied		Area of damage (any degree)	
	10^6 ha	% of total	10^6 ha	% of occupied area
Picea abies	2.886	40	1.477	51
Pinus sylvestris L.	1.470	20	0.866	59
Abies alba Mill.	0.174	2	0.152	87
Fagus sylvatica L.	1.253	17	0.631	50
Quercus L. spp.	0.620	8	0.269	43
Others	0.967	13	0.303	31
Total	7.370	100	3.698	50

SILVICULTURAL PRESCRIPTIONS FOR SPRUCE

Evolution of the principal silvicultural prescriptions in Rheinland-Pfalz

The first comprehensive silvicultural prescriptions were developed in 1843 in Rheinland-Pfalz and South Germany generally. These prescriptions have been steadily refined through experience and new scientific findings. They had been completely revised by 1925 and now exist in a wholly new version, published in 1983 (LFV 1983). This latest revision occupied working groups of forest experts and scientists more than 10 years. The revised silvicultural prescriptions should facilitate the attainment of both economic and management goals.

Application of these prescriptions will ensure that use is made of the latest scientific findings, results of site mapping, theory of forest yield, improvements in planting stock, and opportunities to mechanize. The structure and composition of silvicultural prescriptions have been fully adapted to practical requirements. For either pure or mixed stands, the silvicultural treatments within prescriptions are listed in chronological order from the formation of a stand to its final harvest.

The aim of production

The prescriptions are aimed at producing logs of large dimensions, both diameter and length. Basic to successful management of spruce is a low risk of wind and snow damage. Stands should be managed on rotations of 80-100 or, perhaps, up to 120 years. The current goal is a diameter of 40-50 cm at breast height. Mean annual increment reaches a maximum at about 90 years of age. For site class 1, the mean annual volume increment is 12 m^3/ha at age 100.

Stand types

Norway Spruce is managed mainly in pure stands, but ecological considerations suggest that mixed stands may be more appropriate. The few possible mixtures include spruce with European beech (*Fagus sylvatica* L.) and spruce with black alder (*Alnus glutinosa* L.).

Site requirements

Spruce is grown on moist sites. Nutrient content of the soil is less important than moisture. It is also planted widely on waterlogged soils where, however, it reaches rotation age only when stand density and tending prescriptions are observed exactly.

Establishment of stands

In Rheinland-Pfalz, regeneration of spruce is by planting. Only a few years ago, 4500 or more trees/ha were planted. Now, however, the prescribed planting density is 3500-2700 trees/ha at spacings of 2.0-2.5 x 1.2-1.5 m. Burschel (1981) analyzed plantation performance in relation to planting density and showed that the lower densities gave better results than the higher densities.

Early tending

During the first years after planting, filling-in is usually necessary. On very weedy sites, brush cutters should be used to keep plants free of competing vegetation. Herbicide can still be used[1] against competing vegetation, but it has to be applied for 3 to 5 years, and this is very expensive.

Tending of young stands

Although stand density during establishment is relatively low, precommercial thinnings, followed by commercial thinnings, are relatively early. Precommercial thinnings, especially, use silvicultural models. These have proved useful. After the weeding stage, heavy thinning from below is prescribed for the first thinning. The number of trees is reduced most in the first thinning. Subsequently, lighter, selection thinnings are prescribed. The aim is to obtain some 300-500 crop trees/ha at an average spacing of about 5 m between trees. According to the prescriptions, in 20-year-old stands, 200-300 stems/ha may be pruned to 5 m by handsaws or, at about 25 to 30 years of age, up to 12 m by pruning machines.

Abetz (1970, 1975) examined the main current problem of spruce management, viz., the selection of crop trees in excessively dense young stands. For young stands up to 10 m high, Abetz recommended the use of skidding trails spaced some 25 m apart. The number of trees is reduced by the removal of rows or by a combination of rows and selection thinning. According to Abetz, as much as 50% of the stand may be removed. Early, heavy thinning in the juvenile stage supposedly reduces the danger of breakage from snow and creates stands highly resistant to windthrow. According to Burschel (1981), lack of thinning in young, over-dense stands drastically impairs the subsequent ability to resist snow pressure. Stands in which the stem height:diameter ratio exceeds 80 are considered to be highly susceptible (Abetz 1976).

Proper initial spacing, or early corrective thinning of overcrowded young stands, will produce stable trees that are resistant to snow and wind damage. For reasons of stability, thinning operations should have been completed before the second half of the rotation period. Stabilization of stand boundaries by repeated light thinnings is most important to reduce the risk of windthrow. However, to avoid coarse branching on individual crop trees, gaps > 5.5 m^2 should be avoided in stands younger than 40 years (FVA 1968). Thereafter, the danger of breakage from snow decreases, although that of wind damage increases. After the age of 40, stands should require few thinnings, and crown cover is maintained to avoid creating turbulence.

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[1] Legal when this paper was presented, the use of herbicides to control competing vegetation is no longer permitted.

The preparation of skidding trails and density reduction are carried out with brush cutters or, more commonly, light chainsaws. The workers are paid piecework rates on the basis of stand height and the number of trees/ha to be cut (Rieger 1982).

Thinning: status of mechanization

As the only products from early thinnings are pulpwood and chips, these tending operations inevitably lose money. For this reason, there are good opportunities for rationalization in young spruce stands. This leads to constant conflict between those who believe that soils and stands should be preserved from damage and those who wish to tap the high productive capacity of machines. Many experiments involving the use of large machines have been conducted in Rheinland-Pfalz in recent years. We are currently consolidating. Preservation of the forest soil, particularly on often unstable spruce sites, is identified as the highest priority. In most locations, skidding trails have to be covered with slash for yarding. Forwarders with long-reach booms and high flotation tires carry the pulpwood to roadside, or the booms of processors handle the wood on the trail. However, most of the early thinnings are still man-handled to the skidding trails, then yarded by light machines, such as farm tractors, which cause damage to the soil.

In the attempt to increase mechanization, we use quite a few forwarders and some processors that are designed for Scandinavian conditions and that could damage the fragile spruce sites of our area.

Silvicultural prescriptions limit the use of heavy machines. For this reason, we must constantly seek better silvicultural and harvesting techniques to limit soil compaction, impeded drainage, and other damage to soil. Moreover, after roots have been damaged by heavy equipment, we must now pay much more attention to *Fomes annosus* root rot than we did over the last 15 years.

Practical experiences with silvicultural prescriptions

Up-to-date silvicultural prescriptions have been shown to be very efficient in management practice. They are absolutely necessary when one is devising annual management plans, when silvicultural problems arise after snow and wind damage, and when one is instructing forest trainees. Problems may arise where silvicultural prescriptions conflict with the mechanization of site preparation, planting, and logging. Control of mechanization has not yet reached a satisfactory stage of development.

ESTABLISHMENT TECHNIQUES MEETING SILVICULTURAL PRESCRIPTIONS

Natural Regeneration

Natural regeneration of spruce is successful only on sites with a combination of particularly favorable site factors. Few of these are found in Rheinland-Pfalz. Therefore, silvicultural prescriptions do not cover natural regeneration of spruce.

Planting

Provenance, size of plants

Spruce provides high yields with relatively small expenditures for establishment and tending. In achieving high yields, provenance is most important. In this respect, the silvicultural prescriptions are absolutely binding. Where trees are subject to breakage caused by snow, and for elevations > 600 m, provenances resistant to breakage (e.g., from corresponding elevations in the Black Forest or the Bavarian Forest) must be used.

Normally, scarification is not needed before spruce is planted except where the depth of raw humus exceeds 10 cm. If scarification is necessary, we use the TTS Disc Trencher. On flat sites, we use skidders to rake slash into windrows. On slopes, windrowing is done by hand. If there is no fire danger, slash is burned to avoid insect infestation. At present, this work is done by otherwise unemployed people.

In general, we use transplants 3-4 years old and 40-60 cm tall. Bigger plants are more difficult to establish, but, in some cases, they have the advantage of outgrowing weed competition more quickly. The growing of spruce from root-cuttings is widely undertaken. Most of the planting stock is grown in commercial tree nurseries. Containerized spruce planting stock proved to be unsuccessful in our conditions; the stock was too expensive and usually too small. For this reason, only bare-root stock is used for outplanting.

In spite of planting shock (Dengler 1972) that sometimes affects outplants for several growing seasons, bare-root stock has survived well when carefully planted.

Planting method; piecework wage system

On suitable sites of sufficient size, it is desirable to plant spruce by machine. Here we use small Finnish or Danish planting machines. On slopes, which are common in Rheinland-Pfalz, as well as on smaller areas (up to 1.5 ha) of flat land, angle planting (Fig. 1) has proved to be the best method.

(a) First stroke, with the mattock ax-head; the tool is levered, not drawn.

(b) Second stroke, with the adze head, at right angles to the first stroke; the handle is pushed forward and then to one side to open the planting hole.

(c) The root of the tree is swung into the planting hole.

(d) The mattock ax-head is levered over the upper thigh.

(e) The hole is closed by stepping gently on the surface while one hand holds the tree vertical.

Figure 1. Schematic illustration of angle planting with the ax/adze mattock.

Angle planting is considered to have the following advantages:

- little risk of plants becoming desiccated
- little risk of the plants being heaved by frost
- only minor disturbance of soil conditions and, therefore, little disruption of capillary connections
- relatively low planting costs.

Mortality rates are only slightly higher than in other methods. Angle planting can be used for large bare-root plants, but it is not suited to very rocky soils.

Planting is mainly by piecework. To determine rates, we developed a system based on 80 full-day time/work-studies. The system has been calibrated and adjusted slightly by means of time analyses in three successive years. The system (Fig. 2) allows a basic 600 minutes per 1000 plants, and is applicable to all common species as long as the plants are not more than 120 cm tall. Conditions that increase the difficulty of planting, e.g., heavy vegetation, stones, and raw humus, are compensated for by an additional time allowance.

Depending on local conditions, this system gives a piecework cost of planting a 3-year-old spruce of between 0.30 DM and 0.80 DM. The cost of the seedling is about 0.50 DM.

Hence, the first-year cost (DM/ha) for establishing a spruce plantation may be in the order of:

mechanical removal of slash	400
stock and cost of planting (3500 trees)	3,500
protection against browsing by roe deer	250
	4,150

To this must be added the costs of in-filling in succeeding years and weed control. Compared with those for establishing other tree species, the cost for establishing a spruce plantation is rather low.

SUMMARY AND CONCLUSIONS

Silvicultural prescriptions, an important aid to forest management, take account of human, ecological, and technical factors. Prescription for Norway spruce in a German federal state is presented here as an example. Such prescriptions, developed by forest experts using scientific input based on experimental results, serve as guides for determining the treatment of stands in all circumstances. They provide guidance for the manager and serve as a textbook for the student. A standard format for prescriptions ensures clarity and facilitates adherence to those prescriptions.

Norway spruce suffers extensively from acid rain in Rheinland-Pfalz. Therefore, we must pay special attention to this economically important species in order to secure sustained production of raw timber.

Silvicultural prescriptions allow rationalized mechanization wherever stable soil conditions permit the use of heavy equipment.

Aufnahmeblatt für Winkelpflanzung – gültig ab 1. 10. 1982 –

für Forstrevier

– gültig für Kulturflächen ab 0,3 ha bzw. Pflanzenzahlen ab 600 Stück –

Forstamt _____ Forstrevier _____ Plan-Nr./Waldort _____/_____

Kulturfläche _____ ha Baumart(en) _____ Alter _____ Pflanzenzahl _____ Verband _____

					Minuten je 1000 Pflanzen Vorgabezeit	Aufnahme
1. **Grundzeit** für einfache Verhältnisse						
– Kiefernsämlinge					500	
– übrige Baumarten					600	
2. Zeit für **zusätzliche Arbeiten**						
2.1 Wurzelschnitt	mit Beil				90	
2.2 Schutztauchen					40	
2.3 *(entfallen!)*						
2.4 Platten-(Plaggen-)hacken (mind. 35 cm x 35 cm)					490	
3. **Zuschläge** für erschwerende Arbeitsbedingungen						
3.1 Hangneigung	über 15–25%	10	über 45–55%	70		
	über 25–35%	20	über 55–65%	120		
	über 35–45%	40	über 65%	180		
3.2 Behinderung durch Bewuchs, Dornen, Reisig	Anteil der Arbeitsfläche mit Behinderung					
	0 bis 1/4	über 1/4 bis 1/2	über 1/2 bis 3/4	über 3/4		
– dichter behindernder Bewuchs	0	20	40	60		
– Dornen und Schlinggewächse, behinderndes Reisig	0	60	120	180		
– geschlossene Reisigauflage (mindestens kniehoch, ungeräumte Fläche)	0	150	300	450		
3.3 Behinderung durch Geländemerkmale – Gräben, sumpfiges Gelände, stark lehmige Böden	0	30	60	90		
3.4 Behinderung durch Blocküberlagerung, Geröll, Schutt	0	30	60	90		
3.5 Behinderung d. Flachgründigkeit, organische Auflage						
– Flachgründigkeit, zahlreiche Steine, hindernde Durchwurzelung, starke Bodenverdichtung	0	20	40	60		
– Organische Auflage über 10 cm	0	40	80	120		
3.6 Entfernung zwischen Pflanzeneinschlagsplatz und dem Mittelpunkt der Pflanzfläche	Pflanzengröße bis 60 cm		über 60 cm			
– im Mittel über 150 bis 250 m	30		80			
– für jede weiteren 100 m	30		80			
3.7 Pflanzengröße im Mittel über 60 cm bis 100 cm				40		
im Mittel über 100 cm bis 120 cm				50		
3.8 Pflanzenabstände in der Reihe über 1,50 m bis 3,00 m sowie Nachbesserungen mit einem rechnerischen Pflanzenverband von über 1,50 m x 1,50 m bis 3,00 m x 3,00 m				50		
4. **Zwischensumme** Nr. 1 bis 3						
5. **Abschlag** für Verzicht auf Abstecken der Pflanzenreihen mit Fluchtstäben				/. 70	/.	
6. **Summe** Ziff. 4 ggf. minus Ziff. 5 = Gesamtvorgabezeit je 1000 Pflanzen						

Stücksatz in DM/1000 Pflanzen: _____ (Eckstr.) x 1,15 x $\frac{1}{60}$ x _____ (Vorgabezeit) = _____ (Stücksatz)

Figure 2. Form used for determining piecework wage rates.

Spruce stands will be shaped almost exclusively by hand even in the near future. There is still a tendency toward wider planting spacings. New approaches for the setting of terms for planting work and the treatment of young stands are being considered.

LITERATURE CITED

Abetz, P. 1970. Jungbestandspflege im Zeichen optimaler Stammzahlhaltung. **Forst- und Holzwirt** 25(17):365-367.

Abetz, P. 1975. Eine Entscheidungshilfe für die Durchforstung von Fichtenbeständen. **Allgemeine Forstzeitschrift** 30(33/34):666-667.

Abetz, P. 1976. Beiträge zum Baumwachstum. **Forst- und Holzwirt** 31(19):389-393.

BML. 1984. Bericht des Bundesministers für Ernährung, Landwirtschaft und Forsten, Ignaz Kiechle, zur Waldschadenserhebung 19894. **AID-Informationen** 33(26): not paginated.

Burschel, P. 1981. Neue Erziehungskonzepte für Fichtenbestände. **Allgemeine Forstzeitschrift** 36(51/52/53):1386-1394.

Dengler, A. 1972. p. 154-159 *in* Waldbau, Parey, Hamburg and Berlin.

FVA. 1968. Stammzahlreduzierung in reinen Fichtenjungbeständen. Merkbläetter Baden-Wurttembergischen Forstlichen Versuchs- und Forschungsanstalt No. 8.

LFV. 1983. Vorgabezeiten bei der Winkelpflanzung. Schreiben des Ministeriums für Landwirtschaft, Weinbau und Forsten vom 20.2.1984, File 736.6681.

Rieger, G. 1982. Technik und Zeitbedarf der Jungbestandspflege in den wichtigsten Betriebszieltypen. Mitteilungen der Forstlichen Bundes-Versuchsantalt Wien und Forschungschungsanstalt Baden-Wurttemberg, Heft 98.

Schmidt-Vogt, H. 1977. p.260-265 *in* Die Fichte, Band 1. Parey, Hamburg and Berlin.

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SESSION IV - WORK STUDY TECHNIQUES

WORK STUDY TECHNIQUES IN THE UNITED KINGDOM: APPLICATION IN EVALUATING SILVICULTURAL EQUIPMENT

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INTRODUCTION

The United Kingdom Forestry Commission was founded in 1919 to rehabilitate woodlands devastated by cuttings during the First World War. The organization had dual roles: provision of an advisory and administrative service for private woodland owners, and the creation of a state forest enterprise. Some 30 years later, acquisitions of land for afforestation were increasing, existing plantations were being thinned, and supply contracts between the Commission and newly opened pulp mills were being let. It was against this background of expanding programs of work that the Forestry Commission's Work Study Branch was formed in 1956.

Initially, the Work Study Branch consisted of a small number of forestry graduates, who were trained in work study methods while working in conjunction with firms of private consultants. Early work focused on improving hand tools and their mode of use. Work measurement followed.

By the 1960s, opportunities for mechanization were increasing. The focus of method studies increasingly narrowed on selecting the best machine and the best method of working single- or multiple-machine systems.

The strength of the Branch was increased to enable forest managers throughout Britain to call upon regional Work Study teams for assistance in the transition from labor-intensive manual systems to mechanized systems of

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operation. For about 10 years from the late 1960s, the Branch had its own mechanical engineers and was responsible for machinery research and development. As forest machinery became more complex and mechanical development more costly, this function was largely abandoned, and manufacturers themselves now modify their machines as necessary to suit British conditions. The Work Study Branch now concentrates on evaluating promising production machines or manufacturer-modified versions thereof.

Today, the Branch has 25 work study specialists in five teams throughout Britain. Resources are directed towards method study and work measurement in the ratio of about 4:1.

During the 1960s, labor productivity in Forestry Commission operations rose at a compound rate of more than 6% annually; the 1970s saw further big gains in labor productivity and a workforce reduction of 25% (Anon. 1980). There is undoubtedly considerable scope for further improvement in productivity. Harvesting is still mostly by motor manual systems, but the scene is set for the widespread introduction of processors and harvesters. Similarly, on the silvicultural side, adoption of new techniques (e.g., weeding), as described later in the case study, promises lower costs.

METHOD STUDY

Various standard techniques of industrial method study are used routinely in the Forestry Commission, including flow process charts, multiple activity charts, critical examination and critical path analysis (Anon. 1979).

In the last 3 years, method studies have been conducted in the following areas: nursery operations, including precision sowing techniques, lining-out of seedlings, lifting of transplants, handling of transplants in refrigerated storage, and application of insecticides to transplants; establishment operations, including scarification, fencing, weeding, aerial fertilizing (with electronic positioning guidance for aircraft and alternative formulations of fertilizer), fire fighting (with various helibucket techniques for water bombing and laying of foam fire barriers); and harvesting operations, including the measurement of timber, development of methods of organized thinning and felling, and evaluations of chainsaws, forwarders, processors and harvesters. Some investigations, e.g., the current assessment of the danger to chainsaw operators of exposure to carbon monoxide fumes, are specifically directed towards health and safety.

All Work Study Branch investigations are formally commissioned; objectives and terms of reference are agreed upon at the start of the project. Commissioning staff are normally those in charge of particular functions at Forestry Commission headquarters or regional offices. Work Study Branch resources are therefore directed to the problems defined by line managers; Branch staff do not select their own areas for study. A project plan is approved for each study (Appendix 1). Commonly, a method study raises research questions; many projects are integrated to involve both the Work Study Branch and the Research Division of the Forestry Commission.

Awareness of interactions among operations is increasing. For example, the kind of site preparation can determine the optimal size of planting stock, method of planting, and the need for subsequent weeding. There is a move towards examining groups of related operations or systems.

When investigations have been completed, a report is prepared and presented to the staff member who commissioned the project. If the recommendations are accepted, as they normally are, the new method/system/machine is installed jointly by Work Study Branch and Training Branch staff.

TIME STUDY

Once method studies have been completed, time studies are often carried out to enable the forest manager to prepare work schedules, estimate labor productivity and set times for incentive payment schemes. "Time study is a Work Measurement technique for recording the time and rates of work for the elements of a specified job carried out under specified conditions, and for analyzing the data so as to determine the time necessary for carrying out the job at a defined level of performance" (Anon. 1979).

"Standard performance is the rate of output, which qualified workers will naturally achieve without over-exertion as an average over the working day or shift provided they know and adhere to the specified method and provided they are motivated to apply themselves to their work" (ibid.). On the standard rating scale, standard performance is designated 100; the scale is used by the Forestry Commission and many other organizations around the world. Clear guidelines (Appendix 2) enable levels of performance to be assessed on a scale of 50-150 in five steps (Mobbs 1986).

Basic time is the time for carrying out work at standard rating, and standard time is the total time in which a job should be completed at standard performance, with allowance for basic work content, contingencies, and rest and relaxation (Anon. 1979).

Before a time study is begun, the task must be defined carefully and its components given definite start and finish points. Elements are of three main kinds: **cyclical**, which recur with each work cycle; **other work**, which occurs intermittently (typically maintenance, job set-up, and clean-up work); and **delays** of various sorts, e.g., rest and meal breaks. Currently, most of the Forestry Commission's time studies use continuous timing; data collected with small hand-held terminals are transmitted by telephone to a main computer for analysis. These terminals, which have 32 K of RAM (including about 8 K for program), weigh 900 g, have full alpha-numeric keyboards, quartz clock, and 16-character LED display. On receipt of the data from the terminal, the main computer gives a printout of the raw data, with appropriate error messages; a further printout, in terms of collated basic times, is provided, and both are returned to the study man for checking. Once the requisite range of study data has been obtained, various programs on the main computer are used to obtain the best possible estimates of basic times. A fuller description of this electronic data capture and analysis system is given by Bland-Flagg (1985).

In the Forestry Commission, most operations are done by incentive or piecework. Historically, the level of incentive relative to time wages has fluctuated somewhat. At present, an incentive of about 30% is commonly considered necessary to motivate an operator to achieve standard performance; such incentives can lower unit costs significantly. The Forestry Commission has standard time tables for most of its forest operations.

CASE STUDY - WEEDING

The Work Study Branch was commissioned to examine the Forestry Commission's forest weeding program, to follow up with method studies, and to develop any improved techniques deemed necessary. A survey of all forests in the country was carried out in 1983 to ascertain details of the seemingly excessive 25,000 ha/per annum program, with its direct costs of > £1 million. Results were compared with those from a 1974 survey, and with forecasts for 1988. The main weed type, "grass and herbs", accounted for half of the total program in the two surveys and the forecast. The proportion of hand weeding, 40 percent of the total area, was considered to be excessive. Use of medium-volume herbicide application rates and granular herbicides declined because of poor application technique, ergonomic considerations, and the difficulty of obtaining even coverage with applications of granular herbicide. The putative economic advantage of using herbicides was not materializing. The Work Study Branch, therefore, was commissioned to develop, for the "grass and herb" weed category, herbicide application techniques to improve ergonomics, reduce costs, and secure acceptance by operators and management.

Conservation considerations and economics both favored spot treatment to minimize rates of herbicide applied per unit area. Liquid herbicides were favored because of the great difficulty that had been experienced in trying to improve the distribution of granular herbicide. To improve logistics and promote good ergonomics, very low-volume (Sales et al. 1983) application was preferred, provided that this did not require the operator to wear excessive protective clothing. As a result, interest focused on modified veterinary drenchers, originally designed to administer measured doses of medicine to sheep or cattle.

Forestry Commission requirements were discussed with various equipment manufacturers, and trials with various guns, nozzles, and herbicides were carried out. With a range of herbicides, a dose rate of 5 ml per spot gave good control of vegetation in a patch about 1.1 m in diameter. The small volume of herbicide needed per unit area helped reduce the laden weight of the application equipment from 24 kg for backpack sprayers of conventional design to 6 kg, thereby reducing operator fatigue and easing logistics. Operators had no need of uncomfortable filtering facepieces when spraying because of the droplet characteristics of the directed spray. After successful trials, drench guns were made available to field staff. They were very popular with the 200 operators who used them in the first season. Further minor modifications have been made to improve the spray pattern and eliminate the need to wear a protective jacket when spraying. Cotton liner gloves are recommended to prevent hand blisters, which prolonged operation of the trigger had caused, and it is recommended that the gun be held in two hands to reduce arm ache.

Full time studies of drench gun weeding are currently under way: field managers need productivity information for such new techniques at once (to avoid enshrinement of improper piecework rates in practice, which would make correction difficult), but there is necessarily a time lag before the Work Study Branch can provide comprehensive guidance; there is a learning curve as operators gain proficiency in the use of new techniques. Also, slight modifications are commonly made to equipment and work method on the basis of early experience. As well, it is time consuming to gather time studies representing the full range of working conditions, locations, and operators. Provisional output guidance is therefore based initially on limited studies or synthetic data.

For the drench gun, six time studies were done to establish "other work" element times and their frequencies. "Cyclical" elements were obtained synthetically. The provisional guidance was related to the following conditions: planted trees clearly visible in rows 1.5-3.0 m apart; and materials laid out on site to avoid fetching distances > 100 m. The job was fully specified (Appendix 3), and all tools, equipment, and protective clothing were itemized. The key data for compiling the provisional standard times are presented in Table 1.

Time studies covering the full range of conditions are in progress. Cyclical work will be timed in various conditions differing in vegetation, terrain, brush and harvesting debris, etc. Tables will be prepared separately for different conditions as appropriate. It is already clear from the provisional guide that the drench gun will greatly reduce costs and become a very important piece of silvicultural equipment.

Table 1. Drench Gun – Provisional Standard Times, the basis of the Standard Times table in Appendix IV.

Element	Frequency per day*	Basic minutes per day	Percent rest**
Cyclic Work			
Spraying	–	–	20.5
Other Work			
General preparation	1	1.36	15.0
On/off protective clothing	3	11.34	10.0
Fill applicator	1.9	–	21.0
Walk to and from base	10	5.00	16.5
On/off gloves	2	1.44	13.0
Wash hands	5	6.65	9.0
Empty/clean applicator	1	2.75	16.0
		28.54	

– Weighted mean rest allowance for Other Work = 11.88%

– Limited time studies showed Other Work to be 7% of Cyclic Work, and this was taken as a constant.

– Overall rest allowance percent = $\frac{20.5 \times 100 + 11.88 \times 7}{107} = 19.93$

– Cyclic Time/ha = $\frac{\text{Distance walked/ha}}{\text{Mean walking speed at Standard Performance}}$

– Standard Time = Cyclic Time x 1.07 x 1.1993/ha = 128% Cyclic Time.

*Based on 2–m row spacing and 2500 trees/ha.

**Based on standard rest allowances.

SUMMARY

A historical account of the development of Work Study in the Forestry Commission is given. The present structure of the Work Study Branch and the place of the Branch in the organization are described. The techniques most often used in method study are listed; the Forestry Commission's incentive scheme is explained, and procedures for carrying out work measurement studies are given. A particular case study with a new piece of silvicultural equipment for spot weeding, the modified veterinary drench gun, is described. The method study development with this equipment is detailed, as is the procedure for compiling an output guide.

LITERATURE CITED

Anon. 1979. p. 405-415 *in* Introduction to Work Study, 3rd ed. International Labor Office, Geneva.

Anon. 1980. p.9 *in* 60th Annual Report and Accounts 1979-80. Forestry Commission, Her Majesty's Stationery Office, London.

Bland-Flagg, G.D. 1985. Electronic data capture and analysis in forestry. **Journal of Management Services** 29(8):8-10.

Mobbs, I.D. 1986. Guidelines for work study in forestry. International Labor Office, Geneva.

Sales, J.S.P., Tabbush, P.M., and Lane, P.B. 1983. The use of herbicides in the forest. Forestry Commission Booklet 51, Her Majesty's Stationery Office, London, 78 p.

APPENDIX 1

PROJECT PLAN 010/84/1

Project Famo TSM Transplant Lifter.

Objects:

1. to test the suitability of the Famo TSM single-row transplant lifter for use in FC nurseries in 6-row beds
2. to provide guidance on outputs
3. to develop a system for handling loose-lifted transplants between transplant lines and processing and/or storage areas

Location: Dornoch Nursery N(S)

Project leader: R. G. Muhl

Other involvement:

a. mechanical development - nil
b. statistical - nil
c. silviculturist - consultation on physiological aspects of transplant handling

Costs:

staff time	£
non-industrial 15 man days at £70 per day	1050
industrial 5 man days at £40 per day	200
travel and subsistence	300
cash purchases - Famo TSM transplant lifter	2500
- other	300
conservancy VME	100
Total estimated cost	£4450

Benefits:

1. reduction of transplant lifting and handling costs
2. reduction in labor requirement for lifting and handling transplants at a time of peak demand for labor in nurseries
3. improvements in transplant quality through efficient handling systems

Cross reference with related studies:

010/1/7 - trials of the Zejlstra and Bolhuis transplant lifter
- short trail of the Famo TSM transplant lifter.
010/83/10 - transplant handling systems

Timing: February-March 1984

Commissioned by: Dr. D. B. Paterson, FMD

Approved by: Mr. A. J. G. Hughes

Distribution:

FMD, HQ
Principal silviculturists, (N) and (S)
Conservator N(S)
Chief Purchasing Officer
Chief Work Study Officer
Chief Education and Training Officer
Safety Officer
Work Study Team Leaders

APPENDIX 2

Rating	Description	Example in km/hour walking speeds
50	Slow, clumsy movement, the operator shows no interest and appears half asleep.	3.2
75	Steady, slow and unhurried, but time is not in any way deliberately wasted.	4.8
100	Brisk, efficient, well-planned work. This rate of work can be maintained all day, provided that the operator takes the right amount of rest.	6.4
125	Very fast work. The operator is working at a speed which he is unlikely to be able to keep up all day.	8.0
150	The operator is going flat-out. The quality of work suffers and he will be unable to keep this pace up for very long. This rate is rarely achieved.	9.6

Generally, operators who are skilled and accustomed to doing the job work within the rating range 80-120. Those working outside this range are generally less likely to be useful subjects for time study, because of subtle changes in the working method.

APPENDIX 3

WORKING METHOD

Wearing the appropriate protective clothing, carry out the following operations:

i. Either mix water and herbicide, or shade pre-mixed herbicide.

ii. Fill knapsack and place on operator's back.

iii. Check that drench-gun is adjusted to deliver the correct dose rate of 5 mL/spot.

iv. Prime drench-gun.

v. Apply a few shots, with the drench-gun held at spraying height, and measure spot diameter. If spot diameter is the same as that used for calculating the dose rate, proceed to spray; if not, recalculate.

vi. Walk to row.

vii. Holding the gun's trigger in one hand and supporting the front of the gun in the other, start walking and spray each tree; carry out alternative operation as directed.

viii. Refill when convenient or when knapsack is empty.

ix. Repeat vi. and vii.

x. Repeat v. at various times during the day.

xi. At the end of each day, empty surplus herbicide from knapsack into a clearly labeled container. Wash out and maintain applicator.

xii. At breaks and at end of day remove protective clothing and wash hands.

APPENDIX 4

STANDARD MINUTES PER HECTARE FOR SPOT SPRAYING WITH DRENCH-GUN (EXCLUDING FILL/REFILL TIME)

Distance between rows (m)	Metres walked per minute at standard performance								
	60	55	50	45	40	35	30	25	20
1.5	142.58	155.55	171.10	190.11	213.88	244.43	285.17	342.20	427.75
1.6	133.67	145.82	160.41	178.23	200.51	229.15	267.15	320.81	401.02
1.7	125.81	137.25	150.97	167.75	118.71	215.67	251.62	301.94	377.43
1.8	118.82	129.62	142.58	154.43	178.23	203.69	237.64	285.17	356.46
1.9	111.99	122.17	134.39	149.32	167.98	191.98	223.98	268.77	335.97
2.0	106.94	116.66	128.33	142.58	160.41	183.32	213.88	256.65	320.81
2.1	101.85	111.10	122.21	135.79	152.77	174.59	203.69	244.43	305.54
2.2	97.22	106.05	116.66	129.62	145.82	166.66	194.43	233.32	291.65
2.3	92.99	101.44	111.59	123.99	139.48	159.41	185.98	223.17	278.97
2.4	89.11	97.22	106.94	118.82	133.67	152.77	178.23	213.88	267.24
2.5	85.55	93.33	102.66	114.07	128.33	146.66	171.10	205.32	256.65
2.6	82.26	89.74	98.71	109.68	123.39	141.02	164.52	197.42	246.78
2.7	79.21	86.41	95.06	105.62	118.82	135.79	158.43	190.11	237.64
2.8	76.38	83.33	91.66	101.85	114.58	130.94	152.77	183.22	229.15
2.9	73.75	80.45	88.50	98.33	110.63	126.43	147.50	177.00	221.25
3.0	71.29	77.77	85.55	95.06	106.94	122.21	142.58	171.10	213.88

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MODERN WORK STUDY AND DATA COLLECTION TECHNIQUES

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KEYWORDS: work study, data collection, data entry, hand-held computer, field data

INTRODUCTION

Research time is normally very expensive because researchers themselves do much of the planning, data collection, analysis, and reporting. Often, field work has been completed before results begin to emerge from the data analysis. In those circumstances, poor study planning may be impossible to remedy. However, electronic equipment, in which developments have been rapid in recent years, can have a strong positive effect on this and other aspects of research, especially outdoor studies. In Scandinavia over the last 4 years, cooperative research has worked toward improving work study and other techniques in forest research. This paper discusses some of the results of these efforts.

PROJECT DESCRIPTION

In work studies, clear definitions for the time elements involved are essential. Of course, these have been defined by researchers in every institution at which work studies have been

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conducted, but cooperation among institutions is difficult if definitions are not standardized. Between 1978 and 1982, however, a Nordic project group developed standard time definitions for Scandinavia.

The next step, begun in 1982, was to improve the work study methods themselves. At first, we worked out a set of joint criteria for computer software for forestry work studies. In spite of the many different types of studies being conducted, we found that 80-90% would fit into a 'standard' design. This made the development of software much easier. During this process we also defined many of the specifications for computer hardware, especially those concerning the need for flexibility. A set of hardware criteria was established: a 'work study machine' should be portable, lightweight (1 kg or less), waterproof, very rugged, functional at temperatures down to -20° C, easily operated even by a gloved operator, easily programmed, and easily connectable to a wide variety of microcomputers and mainframes. We then began reviewing the available hardware.

In 1983, these criteria were met by a very limited number of computers. In Europe we found one British and two Swedish makes of hand-held computer. These we obtained for testing. For Denmark, the British Husky Hunter A5 (Fig. 1) met most of our requirements. It is a rugged 'all-in-one' computer with a CP/M-emulating operating system, which permits CP/M object code applications to be run on it.

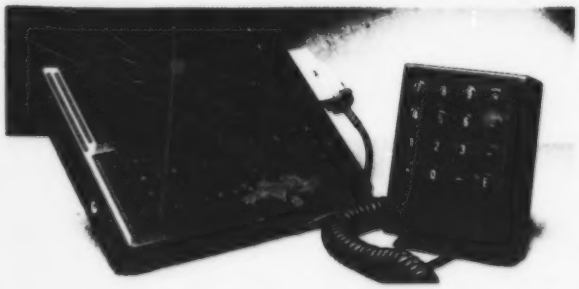

Figure 1. The "Husky Hunter", a hand-held 208 K (RAM) computer.

We soon found that the Hunter did not work properly at temperatures below -5 to -10° C. Heating systems were devised for it. In cooperation with the Norwegian Defence Research Institute, we tested a small charcoal-heated box, which efficiently heated the computer. In Sweden, we developed a carrying case lined with battery-powered heating wires.

RESULTS

The most interesting part of this program is not the 'wonder machines' themselves but what one puts into them, how they are used, and the impact they have on research methods. In this regard, we have developed a number of software systems, e.g., for normal work studies, group-timing-technique (GTT) work studies for people working in teams, and common data collection. All have in common a fixed format of 15 variables per observation, 10 work study time elements, and 5 numeric variables.

The largest program, SIWORK, includes a running calculation of the standard error of the cycle mean. This is used to establish the study size (number of observations) required. SIWORK enables one to compute means and linear regressions for all elements and to graph them directly in the field. We have found these simple yet powerful analyses to be extremely important in making adhoc decisions concerning the study. SIWORK also includes a notepad module for recording remarks. All study elements are shown on a full-screen system, where the user can define function keys. Therefore, no instruction manual is necessary. The researcher is always in full control of the study.

To illustrate the value of the system, a work study in Norway, scheduled to last 18 days in the field according to the 'old' technique, was completed in 12 days with the hand-held computer system, and statistical validity was maintained!

In Denmark, data collected during the day are sent to a mainframe computer by telephone. Thus we secure the database against loss. Quite often we take a microcomputer to the field and begin to analyze data during inclement weather. In this way, we can frequently incorporate improvements into the study, e.g., by refining objectives. Also, the preliminary analyses promote more informed discussion with forest workers.

The main problem now is the human factor. The tractor driver is comfortable inside his air-conditioned cab, and the data are safely in the computer, but the researcher is still outside in the cold and rain. At the Swedish University of Agricultural Sciences, we have developed a GTT frequency study system for motion and ergonomic work studies in which, in addition to a full analysis of work elements, a Finnish procedure enables pulse rate and other physiological data to be fed into the Husky.

SIWORK Work Study System

SIWORK is an example of a system for continuous (to the nearest centi-minute) work study data collection and general data entry. SIWORK consists of two main parts: the study design, and the data (Fig. 2). A study is designed by naming the study elements; this design is saved in a file that can also be used in other studies. The data part consists of three files: the datafile, a file containing remarks, and a file with some running statistics.

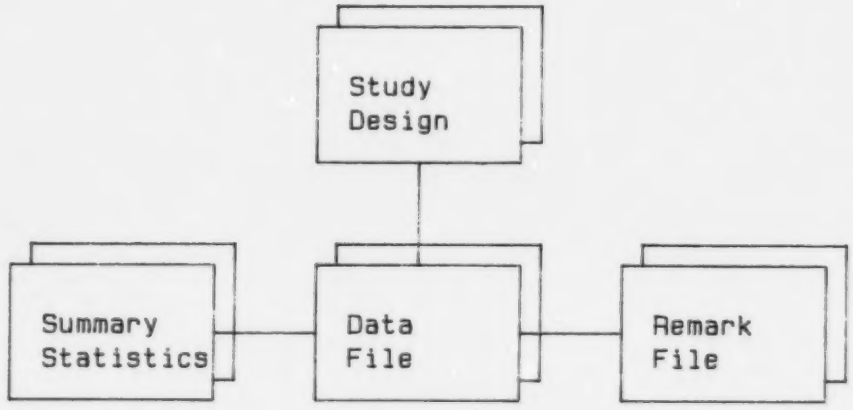

Figure 2. SIWORK structure.

A study can be defined with up to 15 elements or variables. The 15 variables plus the record number and total cycle time (sum of the 10 time elements) are saved in the data file (Fig. 3).

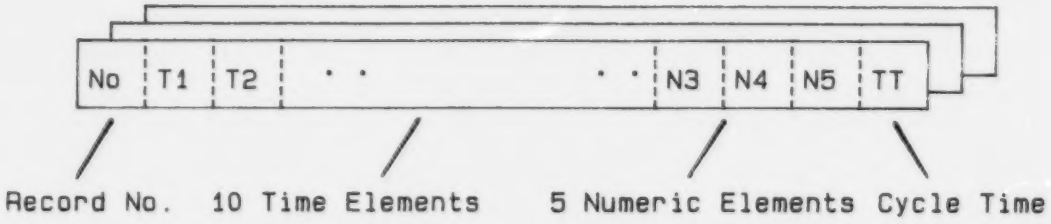

Figure 3. SIWORK record structure.

Those who have worked with data collection, in work study or other research, will know the importance of study control and securing data against loss. Normally, the security is provided by data printouts, from which one can check whether all variables have been measured.

With electronic data collection, all relevant data must be readily available, not hidden somewhere in 'the black box'. It is essential to retain the feeling of security of data given by older methods of collection. A data entry screen from SIWORK illustrates the possibilities of a modern computer (Fig. 4); all 15 variables are shown at one time, including the observation number and the accumulated observation time. Furthermore, the user-defined element codes are shown in reverse video and related to the study element keys. In a time study, the time for an element is recorded simply by pressing the corresponding key when that element has been completed. The time, measured in centi-minutes, is shown on the screen. Thus, the screen serves as a sheet of paper, and at all times the researcher can see what has been recorded.

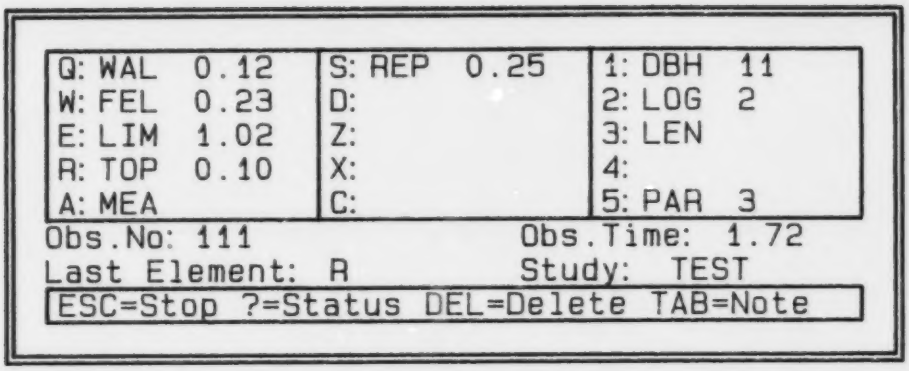

Figure 4. SIWORK Data entry screen.

Each time an observation (or cycle) is entered, by pressing the RETURN key, all elements or variables are saved in the data file, the cycle time is calculated, and various statistics are calculated. The sample size required for any given confidence interval can be obtained at any time by pressing a single key to read the current cycle mean and standard error of the mean. We often use the criterion of a standard error level of 4% as indicative of a sufficient number of observations.

Instead of supplementing the computer with paper notebook jottings, the researcher can use the electronic notepad facility of SIWORK. This notepad, in a file identified with the current observation number, can store remarks up to 40 characters long. During the study, simple calculations of means and standard errors of means can be done for every element or numeric variable. If the study is designed carefully, these calculations are the main part of the analysis. Thus, the researcher can evaluate the study on site and can suggest or carry out modifications to the study during data collection. This has already proved to be a real money- and time-saving facility.

HUFO Frequency Study System

The HUFO system, originally designed to conduct simple frequency studies in nurseries, has been developed into a more complete, general-purpose package. The system includes definition of named elements, up to five numeric variables, and study identification, and it allows the study of body movements (the OWAS system described below) in connection with the element study and analysis.

The measurement frequency interval is user-defined, and the countdown leading to each observation is shown on the screen. After countdown, the user is prompted to enter the element code (a single key) and, eventually, the OWAS code. After the study has been completed, the Husky can be connected to a printer for a printout of the entire analysis.

The OWAS system allows the user to record movement of the observed subject's arms, legs, back, and head, and the force (work load). The various movements are specifically defined. For example, the movements of the back can be registered as straight, bent, twisted, or bent+twisted; and the work load can be defined as < 10 kg, >10 kg, < 20 kg or > 20 kg. The analysis specifies the movements that should be corrected by the frequency of their occurrence.

THE FUTURE

In Scandinavia, we will continue to develop work study techniques through a new joint project. We will also continue work on the use of hand-held computers for data collection (a method we now call 'manual' data collection), but we will concentrate on automation of data input from various transducers placed at vital locations in mechanized logging operations. We will look more closely at study design and planning and at standard statistical analyses for work studies of complex forestry operations.

SUMMARY

Hand-held computers have developed rapidly and can be utilized in research and outdoor data collection. Without these electronic aids, much time is used up in the collection, entry, correction, and punching, of field data before analysis can begin. In Scandinavia, forestry organizations have worked together to test hand-held computers and to develop relevant software for forestry research. One British and two Swedish computers have been tested. The British "Husky Hunter" is now used in Scandinavia. Applications for time studies (continuous and frequency) and general data collection have been developed. On-site analyses can help determine study design and size. The use of computer technology has greatly improved field studies and tends to reduce field work considerably. Careful design of the study application must be undertaken. It is very important that those involved in the study feel completely at home with the data entry process. Cooperation on research methods and study automation is continuing in Scandinavia.

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WORK STUDY TECHNIQUES FOR EVALUATING SCARIFICATION AND PLANTING MACHINES

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KEYWORDS: operating economy, silvicultural equipment, work study techniques

INTRODUCTION

Over the last 15 years, Skogsarbeten (the Forest Operations Institute) has been engaged in a comprehensive research program to evaluate prototype scarifying and planting machines. During this time, we have developed a method of phased working that parallels the development phases of the machines. The research has focused on fields related to technology, methods, and machine economy. Research into biological aspects of the program has been pursued at the Svenska Lantsbruksuniversitet (Swedish University of Agricultural Sciences).

MACHINE PERFORMANCE STUDIES

In the early stages of development, performance of a prototype is assessed in various conditions of operating difficulty. Less frequently, machines already on the market are evaluated for performance. The objectives of machine performance studies are:

- to determine machine performance in relation to stipulated requirements

- to identify any weaknesses in the machines and suggest improvements that might be achieved through further development.

To be able to assess the performance of a machine, we must have a set of clearly defined performance criteria that are generally acceptable to user, researcher, and manufacturer alike. In this context, performance criteria are often defined by our own Technical Advisory Group for Silviculture, or by other project groups in which everyone involved in the development is represented. Some typical factors examined in assessing machine performance are:

Scarification	Mechanized Planting
- mineral soil exposed	- mineral soil exposed
- distance between seedling and edge of humus	- distance between seedling and edge of humus
- possible planting level	- possible planting level
- number of acceptable planting sites	- number of acceptable planting sites
- productivity	- productivity
- machine reliability	- machine reliability
	- planting depth
	- seedling type
	- outplanting success rate

Another important phase of the work is the assessment of terrain conditions, for which a suitable classification system is indispensable. For research purposes, a fairly detailed, descriptive classification system is required. Operationally, a more straightforward, function-related classification system is desirable. However, the values recorded under the two systems must be interconvertible. Skogsarbeten (1969a, 1982) has developed classification systems for both purposes. Much work has been carried out under the auspices of the joint Scandinavian forest work study council, Nordiska Skogsarbetsstudiernas Rådsförsamling (NSR) (Eriksson et al. 1978). The methodology has contributed to a project of the FAO/ECE/ILO Joint Committee (Löffler 1984).

Study methodology

The Skogsarbeten study methodology has been described in a number of publications, e.g., by Bäckström (1978) and Berg et al. (1981). In brief, the studies are generally carried out on 20 to 30 sample plots, each measuring 5 x 20 m. These are located according to terrain difficulty. The machines operate along the length of the plots. Each sample plot is divided into ten 5- x 2-m subplots on which machine performance and terrain conditions are carefully recorded, the latter before the machine operation begins. The work may also involve recording observations on the

machine operation on tape for subsequent transcription in the office. These observations must be clear and concise because the time available for making them is brief.

If necessary, the results of the machine operation are assessed in relation to biological criteria, e.g., seedling survival and growth; this aspect of any study is always conducted in collaboration with the Swedish University of Agricultural Sciences.

An example of this kind of study is that reported by Berg et al. (1981). Four passive scarification machines were assessed for their ability to expose mineral-soil microsites for planting (Table 1). Machines 2 and 3 met the requirements on difficult terrain. The results on easy terrain are inconclusive, because the slash there was deep (class 3).

Table 1. The percentage of exposed mineral-soil microsites for planting, 2 ± 1 m apart, created by four different scarification machines in studies at Kosta and Bräcke, Sweden, 1977/78 (Berg et al. 1981). Boldface values meet requirements.

Terrain difficulty class						Acceptable microsites(%)[a] Scarifier no.				
Ground conditions	Ground roughness	Slope incidence	Stone cover	Slash	Rating	1	2	3	4	Requirement
1–3	1	1	4	3	easy	76	78	84	–	100% for slash cover class 1
1–3	3	1	4	3	difficult	65	**75**	**80**	64	75%

[a] Percentage of planting spots per 50-m single scarified furrow; values in Fig. 1 are derived from several studies carried out between 1975 and 1983.

In all the Skogsarbeten studies, regression analyses showed that slash cover was the factor that most strongly, albeit not significantly, influenced the performance of non-powered scarification units. Hence, there is reason to believe that all units would have achieved the required performance level on easy terrain with slash cover class 1. Nevertheless, the sensitivity of the machines to slash cover was regarded as unacceptable. More recently, machines with powered rather than passive heads have been found to be less sensitive to slash cover (Fig. 1).

The Silva Nova planting machine (formerly known as MoDoMekan), under carefully controlled conditions, was found to be unsatisfactory (Jakobsson 1980); only 73% of the seedlings were planted acceptably. The study showed that more than half of the unsuccessful planting attempts were attributable to shortcomings of the machine. One third of aborted planting attempts were attributable to terrain difficulty, particularly the occurrence of stones.

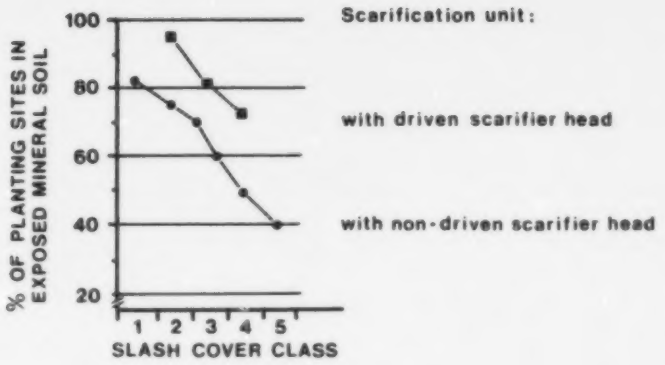

Figure 1. The influence of slash cover on the proportion of planting sites created in exposed mineral soil; data from several studies. Each point represents an average value for performance and slash conditions in the terrain difficulty encountered in the study.

Improvements were made to the prototype and, in a study conducted in 1981, the outplanting success rate was 92% (Sandgren 1982). In that study, only one quarter of unsuccessful planting attempts were attributable to the machine. The factor accounting for most (70%) of the unsuccessful attempts was the incidence of stones; in absolute terms, this was the same as the 1980 level.

In conjunction with the latter study, researchers at the Swedish University of Agricultural Sciences conducted a biological study of seedling survival, comparing seedlings planted by machine with those planted manually (Nilsson and Rülcker 1983). The latter were planted with greater care than is usual in operational practice. One year after outplanting, survival rates averaged 89% for mechanized planting and 93% for manual planting. Differences in survival were correlated with terrain difficulty and can probably be attributed to the adverse effects of stones and slash on the planting machine operation.

PROTOTYPE PRODUCTIVITY STUDIES

Prototype productivity studies are also carried out during an early phase of machine development to provide a basis for estimating productivity levels. The studies are not particularly comprehensive, and the study method varies with the kind of machine. Conventionally, in homogeneous terrain areas, large sample plots, 100 x 100 m, are set out (Fig. 2). Studies of the machine are then conducted to determine effective time, i.e., speed of advance, turning time, and minor delays.

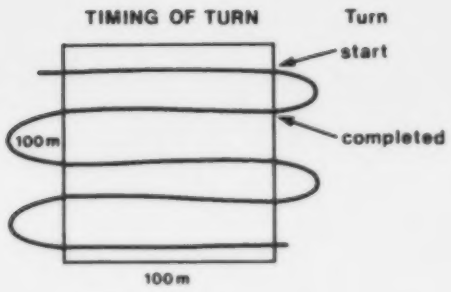

Figure 2. Study method for prototype productivity.

These time studies are generally carried out according to conventional methods, with time clocks graduated in hundredths of a minute (centiminutes), although, in recent years, computerized timing and recording equipment has been used increasingly (Fig. 3).

Figure 3. Datadon 61 computerized time recorder.

These studies, carried out on several sample plots in various terrain conditions, provide the basic information from which to determine:

- the turning time between operating strips,
- the speed of advance of the machine in different terrain conditions,
- the ability of the machine to negotiate the given terrain conditions, which is shown by how well the machine can follow specified routes,
- the nature and extent of short delays,
- the results achieved by the machine in relation to the findings of the performance studies.

This information is valuable in subsequent analyses.

ANALYSIS AND EVALUATION OF THE OPERATING ECONOMY AND PRODUCTIVITY OF A PROTOTYPE

Studies of the operating results and machine performance provide the basis for economic analyses aimed at identifying modifications that might profitably be made to the machine. The objective of this analysis, therefore, is to identify the factors influencing costs. Another important task is to determine suitable uses for the machine in view of its mobility, the size and nature of the sites needing treatment, and the user organization.

Skogsarbeten has developed a software program for calculating costs and manpower requirements for different silvicultural operations. The program treats regeneration as a transportation operation from the edge of the cutover together with all the activities required to end up with an outplanted seedling. Results, assessed two years after planting, are determined on the basis of stocking (Fig. 4).

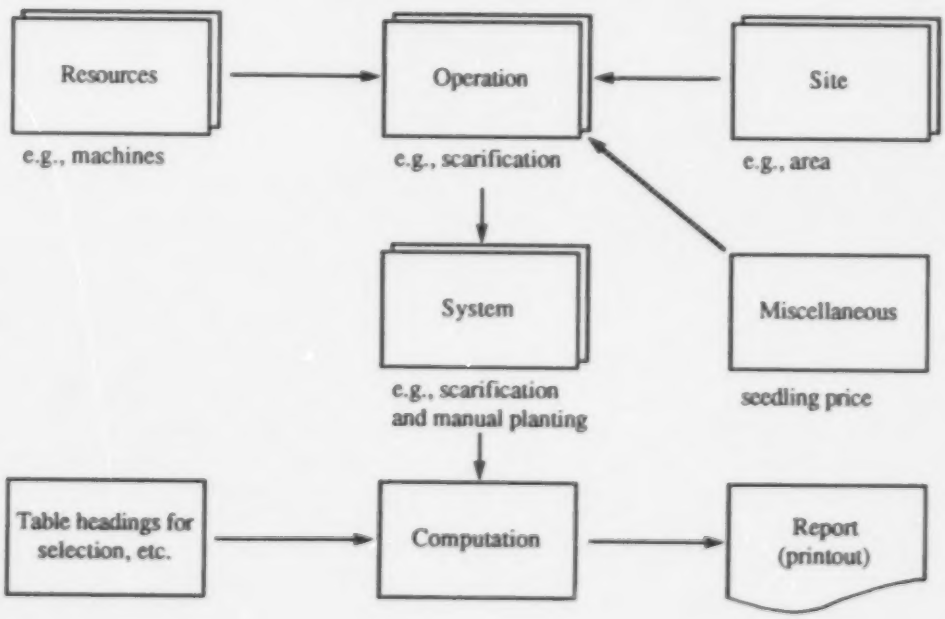

Figure 4. Flow-chart for the Skogsarbeten software program for analyzing costs and labor requirements in regeneration (after Berg 1983).

An approach that has helped elucidate several facets of mechanized planting is illustrated by a study of the impact of machine properties on the overall economy of the Silva Nova planting machine in relation to prototype performance. The study showed that high standards must be met in the success rate for outplanting, operational availability, and speed of advance (Fig. 5). High investment cost and an extra operator on and around the machine were less important. The estimated per-hectare cost of regeneration was derived from the performance of Silva Nova prototypes in comparison with other highly mechanized systems. The analysis showed that machine planting of small containerized stock was hardly any cheaper than mechanized scarification and manual planting (Berg 1983).

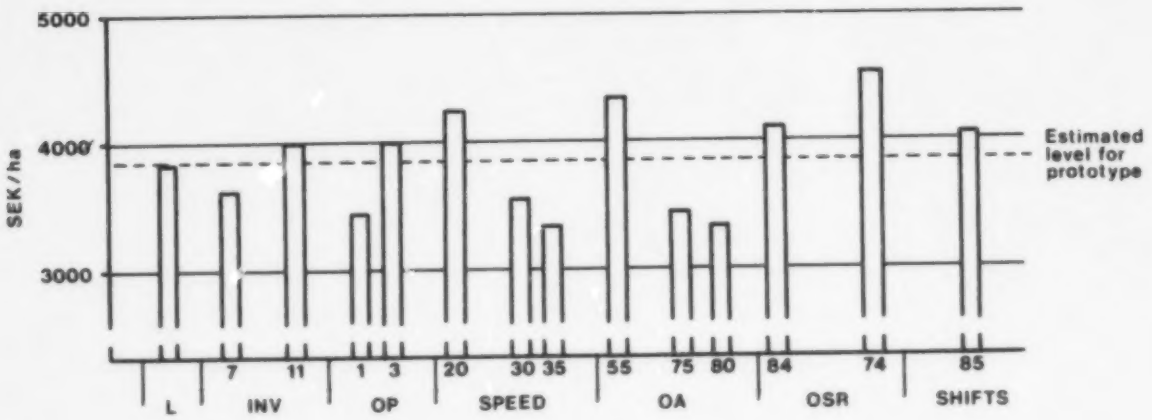

Figure 5. The impact of various machine properties on costs/ha of regeneration.

However, there would appear to be plenty of scope for technical improvements that might reduce mechanized regeneration costs below those of manual methods (Fig. 6).

The results of the study did not substantiate the widely held assumption that mechanized planting would be economical only for large-scale forest enterprises in northern Sweden. On the contrary, mechanized planting was found more likely to be economical in southern Sweden, where the scale of operations is smaller and manual planting faces technical and biological difficulties (Berg 1985).

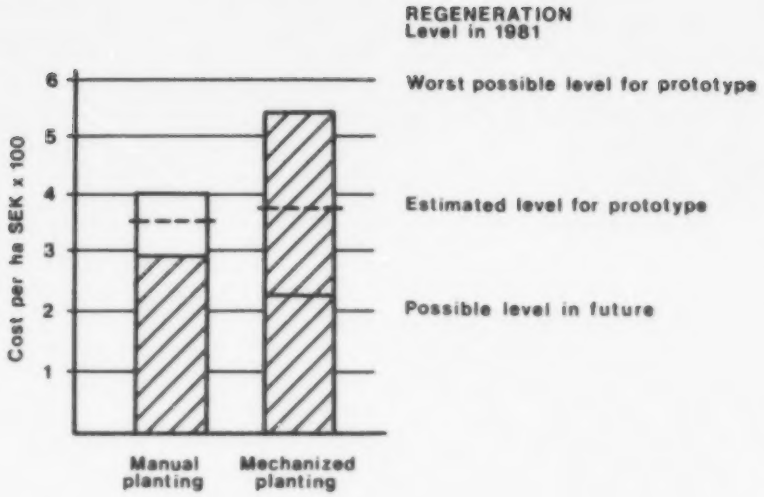

Figure 6. Estimated costs for manual and mechanized (machines with continuous advance) methods of regeneration.

OPERATIONAL FOLLOWUP

Once machine development has produced an operational regeneration machine, followup becomes important. Experience has shown that the breakdowns occurring during operation differ in kind from those occurring during machine development. For a new machine to win early acceptance, the manufacturer must remedy any weaknesses quickly. The necessary followup work is carried out by the user in consultation with the manufacturer and research agencies. In this work, it is essential that the parties involved apply the same definitions to time elements, concepts, and machine parts.

Time concepts in mechanization

Standard terminology for the elements of working time has been used in Sweden for some 20 years (Skogsarbeten 1969a). The system employed corresponds, for the most part, with that in the Forest Work Study Nomenclature (see Anon. 1978) (Fig. 7). In this system, delays that seldom exceed 15 minutes are included in 'Gross Effective Time' (Productive Machine Time). The time limit is indicated by the subscript 't' in E_t. Interrelationships among the different time concepts (Fig. 7) are used to derive various measures of machine reliability, including Mechanical Availability (MA), Machine Utilization (MU), and Technical Utilization (TU).

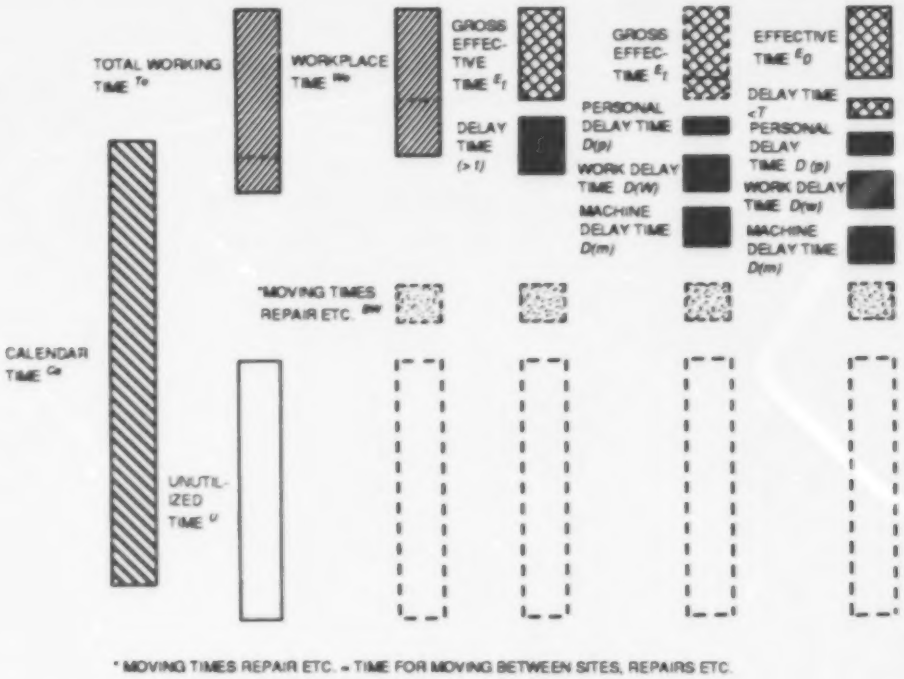
TOTAL WORKING TIME T_o
WORKPLACE TIME T_{wp}
GROSS EFFECTIVE TIME E_t
DELAY TIME (> t)
GROSS EFFECTIVE TIME E_t
PERSONAL DELAY TIME D(p)
WORK DELAY TIME D(w)
MACHINE DELAY TIME D(m)
EFFECTIVE TIME E_0
DELAY TIME <T
PERSONAL DELAY TIME D(p)
WORK DELAY TIME D(w)
MACHINE DELAY TIME D(m)
*MOVING TIMES REPAIR ETC. T_{mr}
CALENDAR TIME T_c
UNUTILIZED TIME U
* MOVING TIMES REPAIR ETC. = TIME FOR MOVING BETWEEN SITES, REPAIRS ETC.

Figure 7. Relationship between the various time concepts in forestry work science (NISK 1978).

$$MA = \frac{\text{effective time}}{\text{time (effective + repair + machine delay)}}$$

Mechanical availability is the availability governed by technical factors associated with the machine. The term is suitable for use in determining the extent of repair work.

$$MU = \frac{\text{effective time}}{\text{time (effective + repair + unavoidable delay)}}$$

Accordingly, Machine Utilization is a measure of availability when certain operational factors associated with the method concerned are also taken into account. Note that the denominator excludes delays that are unforeseeable and, hence, unscheduled.

The measure of reliability most commonly used in Swedish forestry is that of Technical Utilization (TU). This is a measure of availability governed by both technical and operational factors. It is suitable for use in both operational work planning and followup assessments of proven machine systems.

$$TU = \frac{\text{effective time}}{\text{total working time}}$$

Operational time recording

In operational followup, a Kienzle time recorder is usually used. In recent years, programmed hand-held computers, such as the Micronic, have been used (Fig. 8).

Figure 8. Micronic hand-held computer.

In existing applications, the computer records machine vibration. By means of a built-in clock and computer logic, the computer can distinguish between operating and delay time. However, when work is interrupted, the operator must key-in the class of interruption causing the delay. The contents of the memory of the hand-held computer are readily transferable to the memory of a larger computer for continuous followup. The system is currently being used on a limited scale with forwarders. After some modification of the software, these computers will be used on planting machines now being tested in Sweden.

OPERATIONAL STUDIES

Operational studies of a mechanized method are carried out during a late phase of machine development. Data from such studies are used to improve the organization of mechanized operations. Such studies may also identify a need to develop ancillary equipment to enhance the operational efficiency of the machine.

Operational studies were carried out on the Silva Nova planting machine during the 1985 regeneration season. In those studies, all the necessary work associated with the machine was examined (Table 2). The time taken for the various operations was recorded, and the work elements were analyzed to provide the basic information necessary for further methods development work.

Table 2. Functions studied in the operational study of the Silva Nova planting machine in 1985.

Main functions	Ancillary functions	Resources
seedling supply	seedling care	machines, vehicles,
planting	machine maintenance	tools, and equipment
moving between sites	checking results of work	personnel
	detailed planning	

RESEARCH AND DEVELOPMENT WORK AND ITS FINANCING

Research and development work on planting machines is often made more difficult by the biological considerations and problems that must be examined and resolved in parallel with the technical work. A further difficulty is that trials and tests generally can be conducted only during the growing season. Consequently, the development period for these machines tends to be more prolonged than that for logging machines. Hence, a project that initially seems very promising might become uneconomical, if conditions in the outside world change sufficiently during development.

The market potential for silvicultural machines is often more limited than that for logging machines. The lengthy period of development work, coupled with the uncertainty of the market, makes difficult the financing of development projects. The greatest problem is that of securing the financial support necessary for the individual phases of the project.

In Sweden, it is customary for the manufacturer and the prospective user to finance the project jointly. In addition, some form of government grant for the work is usual. The research institutions in Sweden never support such projects financially, although, being themselves funded by the forestry sector and the government, they participate without charging for their services. On the whole, the collaboration among manufacturers, users, and research institutions is successful.

SUMMARY

During the last 15 years, Skogsarbeten (the Forest Operations Institute) has been involved in an elaborate research program to evaluate scarification and planting machines. A method of phased research has been devised to parallel the different phases of machine development.

The first phase, as an aid to the manufacturer, involves conducting work studies aimed at identifying shortcomings in the operation or mobility of machine prototypes. The second phase involves small trials to evaluate the potential productivity of a prototype. The third phase involves analysis of the data collected in the first two phases. The findings of these economic and technical analyses are useful aids in identifying potential improvements to machine design or operations to promote cost-effective productivity. A later phase, involving a followup study of operating practice, is conducted cooperatively among user, manufacturer, and research organization. The main purpose of these latter studies is to obtain reliable data for planning of full-scale operations.

The work studies are performed according to conventional time study techniques. The data are presented in accordance with a Scandinavian system of time definition that has been largely accepted by the forestry sector. The research covers many years and depends on the full cooperation of the parties concerned. The main problem generally is to obtain financing for developmental work by the manufacturer while the commercial viability of the machine remains in doubt.

ZUSAMMENFASSUNG

Während der letzten 15 Jahre hat Skogsarbeten (die Forschungsstiftung für Waldarbeit) an einem umfangreichen Forschungsprogram gearbeitet, das die Auswertung von Prototypen zu Bodenbearbeitungsgeräten und Pflanzmaschinen untersucht. Im Laufe der Jahre ist eine Studienmethode ausgearbeitet worden, die in mehreren Etappen, angepasst an das jeweilige Entwicklunsstadium des Maschinenprojektes durchgeführt wird.

In der ersten Etappe werden Arbeitsstudien durchgeführt. In diesen sollen Mängel des Prototyps, die dessen Funktion und Geländegängigkeit anbelangen, festgestellt werden. Die Resultate dieser Untersuchungen kommen dem Hersteller zu Nutzen. In der zweiten Etappe werden einfache Leistungsstudien durchgeführt, um eine groben Eindruck über das Leistungsniveau der Maschine zu erhalten. In der dritten Etappe werden Analysen unter anderem mit Hilfe von Untersuchungsresultaten aus der Etappe eins und zwei ausgeführt. Durch ökonomische und technische Analysen sollte man angeben können, welche Veränderungen an der Ausformung der Maschine und ihrem Arbeitsmuster vorgenommen werden müssen, um eine möglichst kosteneffektive Produktion in der Waldpflegearbeit zu erreichen. In der nächsten Etappe werden in Zusammenarbeit mit dem Anwender

und dem Hersteller Betriebsstudien durchgeführt, um genügend Unterlagen für Leistungsprognosen und Planungsunterlagen für die praktische Inbetriebnahme der Maschine zu erhalten.

Zeitstudien werden mit Hilfe von konventioneller Zeitstudientechnik durchgeführt. Die Daten werden gemäss einem nordischen System für die Zeitdefinition für Maschinenarbeiten präsentiert. Diese Forschungseinsätze müssen über eine lange Zeit stattfinden. Es ist deshalb von grosser Bedeutung, dass die Zusammenarbeit zwischen dem Forscher, dem Hersteller und dem Anwender vertrauensvoll ist. Es ist oft ein grosses Problem die Entwicklungsarbeit des Herstellers finanzieren zu können bevor man sicher ist, dass die Maschinenidee allgemein als kommerziell attraktiv angesehen wird.

LITERATURE CITED

Bäckström, P.-O. 1978. Maskinell plantering: förutsättningar, teknik, prestationer och kostnader. Forskningsstiftelsen Skogsarbeten, Meddelane 13, 74 p.

Berg, S., Bäcke, J. and Jonsson, C. 1981. Markberedningsförsök i Kosta och Bräcke. Forskningsstiftelsen Skogsarbeten, Redogörelse 2/81, 28 p.

Berg, S. 1983. Mekaniserad plantering. Forskningsstiftelsen Skogsarbeten, Redogörelse 5/83, 46 p.

Berg, S. 1985. Mekaniserad plantering på tre typförvaltningar -- en beräkning. Forskningsstiftelsen Skogsarbeten, Redogörelse 2/85, 20 p.

Eriksson, T., Nilsson, G. and Skråmo, G. 1978. The inter-Nordic project of forest terrain and machines in 1972-1975. **Acta Forestalia Fennica** 164, 61 p.

Jakobsson, R. 1980. Pilotstudie av prototyp för maskinell markberedning - plantering. Forskningsstiftelsen Skogsarbeten, stencil 1980-06-23, 10 p.

Löffler, H. 1984. Terrain classification for forestry. Final report to the joint FAO/ECE/ILO Committee on Forest Working Techniques and Training of Forest Workers, TIM/EFC/WP.1/R.51, Geneva, 46 p.

Nilsson, T. and Rülcker, C. 1983. Planteringsdjup och plantöverlevelse vid maskinell plantering. Institutionen för Skogsskötsel, Sveriges Lantbruksuniversitet, stencil 1983-02, 38 p.

Nisk. 1978. Nordisk avtale om skoglig arbeidsstudienomenklatur. [Forest Work Study Nomenclature] Norsk Institutt for Skogsarbeten.

Sandgren, M. 1982. Arbetsresultatstudie av ModoMekans planteringsmaskinen prototypstudie hösten 1981. Forskningsstiftelsen Skogsarbeten, stencil 1982-07-29, 48 p.

Skogsarbeten 1969a. Tidsbegrepp för maskinarbeten. Forskningsstiftelsen Skogsarbeten. Handledning. 12 p.

Skogsarbeten 1969b. Terrain classification for Swedish forestry. Forskningsstiftelsen Skogsarbeten. Report 9, 11 p.

Skogsarbeten 1982. Terrängtypsschema för skogsarbete. Forskningsstiftelsen Skogsarbeten. Handledning. 28 p.

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THE ANALYSIS AND INTERPRETATION OF FOREST WORK STUDY RESULTS

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KEYWORDS: job specification, method study, rate of working, allowances, standard time

INTRODUCTION

The results of forest **work studies** (British Standards 1969) of stand establishment operations are presented in so many different ways nationally and internationally that interpretation of the results by others is fraught with difficulty. Within IUFRO, members of Working Party S3.02-01 (Stand Establishment Operations) should find a way of presenting internationally comparable work study results to facilitate analysis and interpretation.

Work study is a management service based on those techniques, particularly **method study** and **work measurement** (British Standards 1969), that are used in the examination of human work in all contexts and lead to a systematic investigation of all resources and factors affecting the efficiency and economy of the situation being reviewed in order to effect improvement. The aim of this paper is to shed light on present-day problems associated with the analysis and interpretation of the results of **forest** work studies on stand establishment operations in order to facilitate the understanding of such results.

WORK STUDY TERMS

Observed time

The information first needed in work studies of forest operations is usually the **observed time**, i.e., "the time taken to perform an element or combination of elements obtained by means of direct measurement" (British Standards 1969). For some purposes the data obtained from payrolls might be sufficient, although the time an operator has spent per unit produced is normally determined by stop-watch and work difficulty class. The observed time for a large number of operators measured over a long period provides useful information for calculating the labor and machine requirements of operations planned for the following work season.

The observed time, even when expressed as an average for a large crew, provides no information about whether the average productivity of a crew should be regarded as good or poor. For such purposes the **standard time** (British Standards 1969) for the operation is needed as a comparison. However, the observed time can show the extent to which the productivity of one crew is higher or lower than that of another during a given period in a work difficulty class, or the change in productivity of the same crew at different periods in a work difficulty class. Observed time does not explain any subsequent differences in productivity.

All the work study concepts published by the Forest Engineering Research Institute of Canada (FERIC) (Heidersdorf and Folkema 1976) and included in the Nordic Forest Work Study Nomenclature (Norsk Institut Skogforsk. 1978) are related to observed time only. Consequently they can be used only for comparing operators, not methods or machines or the effect of work difficulty classes on work methods, unless the operator's rate of working has been checked continuously and been found to be constant, and unless all avoidable work **elements** (British Standards 1969) and delays have been excluded (Appelroth 1980). It is very difficult to force even one operator to maintain a constant **rate of working** (British Standards 1969); with more operators, the difficulties increase.

Conventional analyses of variance cannot be applied in work studies if only the observed time has been calculated. Consider the following. If 100 men ran a given distance wearing heavy boots, and then at half that speed walked the same distance wearing light jogging shoes, the observed time would show that they moved twice as fast in the first instance. The conclusion commonly, but erroneously, drawn from such data, which are based on observed time only, is that the distance would always be traveled twice as fast by men wearing heavy boots than by men wearing light jogging shoes, i.e., that the difference in travel speed is attributable to the difference in footwear, with high degrees of accuracy and probability. In this example, the only correct conclusion to be drawn from the observed time is that the men were for some reason motivated to move at a different speed when wearing heavy boots than when wearing light shoes. The inclusion of standard times would, however, make clear that the difference was not due to the wearing of different shoes. Similarly, if 100 people drove Volkswagen Beetles from one place to another at an average speed of 100 km/h and the same people then drove Rolls-Royces the same distance at an average speed of 80 km/h, it would be incorrect to interpret this as indicating that a Volkswagen is faster than a Rolls-Royce. The data merely tell us that the same drivers were for some reason motivated to drive the Volkswagens faster than the Rolls-Royces.

Forest trees react in a compulsive fashion to environmental factors, while operators, in contrast, react in an optional manner. Trees cannot decide on Monday afternoon: "I don't want to grow now despite the fact the growth conditions are ideal". The forest machine operator, however, if he is so motivated, can merely decide to sit and listen to the song of the birds, despite an ideal work environment.

Job specification

To be able properly to analyze and interpret the results of forest work studies, we need to know the job to which the information given on time and cost is related. In each case, the work content depends more on the operator, his skill, experience, habits, and work sequences, and on avoidable delays and work elements, than on the tool or machine being used or the work difficulty classes. Even the productivity of a fully automated machine, which does not require an operator, depends on how it has been programmed. It is therefore necessary to describe in sufficient detail the work reviewed. The same work method can be applied with different tool or machine alternatives. Furthermore, different work methods can be applied with the same tools or machines. This means that it is not enough to describe a method by mentioning only the tools or machines used to carry out the work. The ideal situation is to describe each sequence and type of movement in sufficient detail that they can be repeated by anyone who follows the description. Flow process charts, outline process charts or simo charts (Wittering 1973) illustrate and define work methods.

Work difficulty classes

It is impossible to interpret foreign work study results and then compare them with one's own if the information concerning work difficulty classes is of a general nature, e.g., if terrain is described as easy, medium, or difficult. A terrain classified in The Netherlands as difficult could be classified in Switzerland as easy. Measurable parameters, such as those employed in the terrain classification for Great Britain (Rowan 1977), the Nordic forest terrain classification (Eriksson et al. 1978, Berg 1982), the Canadian classification (Mellgren 1980), and the recent ECE/FAO/ILO Joint Committee Report (Löffler 1984), should be used.

In addition to the difficulties set by the environment, work sequences may be complicated and may include many simultaneous sub-operations. Even here we may talk about work difficulty in the sense of the complexity of a work method that the operator has to use. Such a method requires a very high level of skill and knowledge on the part of the operator.

Method study

Method study is the "systematic recording and critical examination of the factors and resources involved in existing and proposed ways of doing work, as a means of developing and applying easier and more effective methods and reducing costs" (British Standards 1969). Even though a forest worker may have performed a particular kind of work over a period of many years,

that work may still include unnecessary work elements, avoidable delays, and inefficient work sequences; and the manner in which the work is done may be unnecessarily uncomfortable for the worker. Method studies often reveal that even experienced operators work in a way that can be improved considerably. A systematic method study is necessary in order to find the best way of doing a job. Ergonomic aspects are included in the method study. Machines can often be adjusted in many ways. All combinations of equipment adjustments and working rates must be covered systematically before we can determine how optimal work quality can be achieved with each method. Without this we cannot know if the work quality would be better or worse with other adjustments or if the rate of working could have been higher or lower. A systematic method study would provide information about site preparation, for example, such as alternative kinds of site preparation that are possible with a given machine with different adjustments or different rates of travel. It is not possible to tell which work method is better before the alternative methods under review have been standardized by a method study. Instructions on how a method study should be carried out are given by Wittering (1973) and REFA (1984). Through method study, one can improve efficiency by dispensing with unnecessary work, avoidable delays, and other forms of wasted effort or time (Wittering 1973) by improving:

- organization and planning
- working techniques
- the use of manpower, material and equipment
- working conditions
- design or product specifications

It should be emphasized that the work method found to be most suitable in one country or area may be unsuitable in another. In areas with high unemployment and a shortage of capital, a labor-intensive method is usually rational, whereas in areas with labor shortage, an abundance of capital, and cheap energy, a high degree of mechanization is usually best.

Standard performance

Standard performance is "the rate of output which qualified workers will naturally achieve without over-exertion as an average over the working day or shift provided they adhere to the specified method and provided they are motivated to apply themselves to their work" (British Standards 1969). Few countries have qualified workers in abundance. Qualified workers are those with the necessary physical attributes, intelligence, education, skill, and knowledge to carry out the work in hand while meeting satisfactory standards of safety and output (British Standards 1969). If the operator is not qualified, the work method will be interpreted incorrectly.

The standard performance (rated at 100) used by the Forestry Commission in Great Britain is defined as equivalent to a walking speed of 6.4 km/h, the businesslike performance of an average, trained pieceworker who puts his back into the job. This speed will be maintained during a normal working day provided that he takes proper rest (Wittering 1973). The same standard (100 = 6.4 km/h) has been used in Finnish forest work studies (Appelroth 1982a).

In forest work studies carried out in the Federal Republic of Germany, the standard performance of 1.00 is equivalent to a walking speed of 4.8 k/h (Böhrs 1959). This speed, which equals the British Forestry Commission's rate of 75, is defined as steady, deliberate, unhurried time performance, as of a worker not on piecework but under proper supervision; the worker looks

slow but is not intentionally wasting time while under observation (Wittering 1973). There is no more conflict between these two scales than there is between the use of the Celsius and Farenheit scales for temperature. When interpreting forest work study results, one should pay attention to the definition of standard performance that has been used. It is then quite easy to convert the data for analysis and comparison with those of other reports. It is difficult and even unnecessary to attempt to make countries change their standards.

Rating

To **rate** is to "assess the worker's rate of working relative to the observer's concept of the rate corresponding to standard rating. The observer may take into account, separately or in combination, one or more factors necessary to the carrying out of the job, such as: speed of movement, effort, dexterity, consistency" (British Standards 1969). The productivity of an operator who is working according to a given method depends mainly on his rate of working, the amount of time he spends on breaks, and avoidable work elements. Thus, the productivity of an operator can be anything between zero and a maximum. Therefore, information on the rate of working is needed before we can draw conclusions about the productivity of a work method. The maximum productivity of an operator is limited by an interaction of the operator, the prime mover, the machine, and the work difficulty factors.

The rate of working varies widely and quite irregularly, not only among operators, but also for the same operator carrying out the same job from one minute, hour, day, or week to another (Appelroth 1982a). There is, therefore, no way of predicting an operator's rate of working in advance; nor can one generalize, because the operator may be motivated at any time to choose any rate within his physical limits. Rate of working must therefore be recorded continuously as an unavoidable part of work measurement. Unfortunately, no automatic methods are available for recording numerically the operator's rate of working in the forest. The time study man has to be properly trained and his rating must be continuously checked for consistency. When a study is short, films or videotapes may be taken to record the performance rate (Appelroth 1982a). When such a film is projected in parallel with a rating film, accuracy within 5% can be obtained easily. Rating has been applied in forest work studies in Germany since 1926 and in Great Britain since 1956. An informative seminar reviewing rating of forest workers was held at Hessen, the Federal Republic of Germany, in 1983 (Backhaus 1984).

Many attempts have been made to avoid rating, because of the high professional skill it requires of the work study man. In the Nordic countries, so-called "comparative" time studies have been used for this purpose (Makkonen 1954). Surprisingly, they are still applied today. This is unfortunate because comparative time studies are based on the erroneous assumption that an operator's rate of working is constant. Analyses of differences between work methods, tools, or machines, using the comparative time study method (based only on observed time measured directly) are incorrect and misleading, since, as discussed, rate of working is optional and can vary unpredictably between zero and a maximum for a given operator (Appelroth 1982a). Nor is it justifiable to analyze, for example, the effect of work difficulty classes on the observed time of a job, because it is also wrong to assume that the operator's rate of working will remain constant in all work difficulty classes. A recent example of such an error is the use of only the ratios of the directly measured observed times for analyzing the effect of work difficulty classes on different planting methods (Häggblom and Kaila 1982) when all the information about how the operator's rate of working has varied in different work difficulty classes and with different

planting methods is missing and has not been recorded at all. Such conclusions about work methods by difficulty classes represent faulty interpretation of the observed times. The conclusions can be generalized and applied neither to the same operators at another time nor to other operators. Rating is unavoidable when conclusions are needed about the effects of work difficulties or when work methods are compared.

In machine operations, rating should be limited to times controlled by the operator. As far as the time controlled by a machine is concerned, a systematic method study should be used to determine the maximum achievable velocity or rate of working of the machine, consistent with acceptable risk of machine breakdown, work quality requirements, and ergonomic standards for the operator. If the velocity or rate of working is much below the maximum, then the information obtained about the output cannot be used as a standard for comparison of either methods or machines, only for comparing operators.

Allowances

Basic time is "the time for carrying out an element of work at standard rating, i.e. (Observed time x Observed rating)/Standard rating" (British Standards 1969). Allowances are added to the basic time in order to obtain the standard time.

Relaxation allowance is "an addition to the basic time intended to provide the worker with the opportunity to recover from the physiological and psychological effects of carrying out specified work under specified conditions and to allow attention to personal needs. The amount of the allowance will depend on the nature of the job" (British Standards 1969). The analysis of the directly recorded observed times shows that the time spent in resting may vary tremendously from day to day even for the same operator (Appelroth 1982a). Hence, it cannot be accepted that unlimited time per day or shift is needed for rest; there must be a limit. Agreements about rest time are sometimes made between employer and employee. The Forestry Commission (1978) in Britain has examples of rest time allowances and how to calculate them.

In the Federal Republic of Germany there are guidelines for calculating relaxation allowances for forest operations (KWF 1976-1985). A review of such principles is also available (Nguyen 1982). If the time actually spent on rest exceeds the relaxation allowance, the excess must be considered an avoidable delay. Furthermore, operators may, for one reason or another, be motivated not to use in full the agreed relaxation allowance. Such a situation easily results in faulty interpretation of the directly measured observed times. For convenience, the relaxation allowance is calculated as a percentage of the basic time and called the rest factor. Different relaxation allowances are needed in different countries for a variety of reasons, e.g., high elevations, extreme temperatures, and differences in terrain.

The **contingency allowance** is "a small allowance of time which may be included in a standard time to meet legitimate and expected items of work or delays, the precise measurement of which may be uneconomical because of their infrequent or irregular occurrence" (British Standards 1969). It includes such things as: tool breakage involving replacement rather than on-site maintenance; moving equipment to let vehicles pass on the road; and bogging of tractors.

Standard time

Standard time is "the total time in which a job should be completed at Standard Performance -- i.e., work content (total), delay contingency, unoccupied time and interference time where applicable" (British Standards 1969). When standard time is correctly calculated and converted to operation costs, the best work method alternative can be selected. British forest work studies are based on principles similar to those used in the classical German forest work studies conducted early this century. A somewhat outdated publication on the German Kuratorium für Waldarbeit und Forsttechulk forest work study principles is available in English (KWF 1964).

Work study specialists should avoid becoming involved in wage negotiations. In many countries, employers and employees are not bound to the standard times. However, the available standard times are often helpful in reaching agreement on wages. The observed time (or average output) of an operator may differ considerably from the standard time. When operators work at a rate less than the standard performance level, observed time will exceed standard time. The same applies when an operator spends more time for rest than the approved relaxation allowances (excess = avoidable delay) or when he is not properly trained for the job (unnecessary work). Conversely, observed time may be less than the standard time when an operator is motivated to work at a rate higher than the standard performance level, spends less time for rest than the agreed relaxation allowance, and/or is exceptionally skilled at the work in question.

The extent to which standard times can be produced for operations depends on the duration of the study. In most forest operations there is a good deal of day-to-day variation, and the study should normally last one week, e.g., for plantation work (Wittering 1973).

Normally, standard times are produced for operations which continue for a long time on the same work site, e.g., those presented in the British Standard Time Tables and Output Guides (Forestry Commission 1978). Standard times may also be produced for a work shift instead of just for a method as a whole. The time required at the beginning or end of a shift may necessitate the inclusion of a constant, calculation of which should be based on study over several months. In machine operations, calculations of the time required at the beginning or end of work at a work site should be based on a large number of work sites throughout the study (Appelroth 1982b). In this way the capacity of a machine can be calculated on an annual basis, and the number of machines needed to accomplish a year's work can be determined.

Operation statistics

Long, unavoidable production interruptions that occur infrequently are difficult to predict and calculate. These include serious breakdowns requiring major repairs. Reliable statistics on such events may take many years to obtain. For such incidents, only the average duration multiplied by the frequency of occurrence should be included in the standard time per unit produced. Otherwise, most of the elapsed time of a study might derive from such incidents and, consequently, the results would be misleading.

Operation statistics are normally recorded by Quinzle or Servis recorders. The shortest interruption recognized may be set at 15 minutes, as is normal practice in the Nordic countries. **The productive time**, which includes delays up to a maximum of 15 minutes, is called the **gross**

effective time in the Nordic countries (Norsk Institut Skogforsk. 1978). In the analysis of gross effective time, attention should be paid first to the frequency and second to the average length of these unrecorded delays. It makes quite a difference to the output if several 14-minute delays each hour or only a few one-minute delays each work shift are omitted.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Because forest work studies are carried out and reported upon in many different ways, problems arise in analysis and interpretation of results. Currently, much important information is omitted from reported results of work studies. This causes problems in the interpretation of foreign work study results. Often, the information presented has been collected in a manner that does not justify drawing conclusions presupposed by the aim of the study. There is an obvious need to faciliate the analysis and interpretation of forest work study results. International cooperation among IUFRO members would be helped greatly if forest work study concepts with internationally agreed upon definitions were used. Those used by the Forestry Commission in the United Kingdom and by REFA and KWF in the Federal Republic of Germany are a good beginning. The Nordic work study concepts, based on observed time only, permit comparison only of the productivity of different operators or of the same operators over different periods of time. There is no justification for comparing work methods or machines on the basis of the observed time only, unless continuous recording has shown that a constant rate of working was maintained throughout a study. In order to ensure that, for each work element, a constant rate of working is maintained throughout a study some form of rating is unavoidable. The effect of work difficulty classes cannot be calculated for observed time because an operator's rate of working varies considerably over time and between difficulty classes. These classes should be measured and presented according to international norms. Work content should be standardized and a systematic method followed by a trained operator. Productivity depends mainly on an operator's rate of working and the number of avoidable delays that occur in the presence of the work study man. Only qualified operators familiar with standardized work methods should be subjected to work measurement aimed at obtaining standard times. Rational selection of the work methods can be made only on the basis of standard times. Short time studies are of limited use; longer studies are needed to assess the occurrence of infrequent events. IUFRO Working Party S3.02-01 (Stand Establishment Operations) is concerned with only one special field of forest work studies. It is therefore recommended that IUFRO Working Party S3.04-02 (Work Study, Payment, Labor and Productivity) analyze and make recommendations on international forest work study concepts and definitions.

ZUSAMMENFASSUNG

Die Ist-Zeit kann nur beim Vergleich der verschiedenen Arbeiter oder derselben Arbeiter zu verschiedenen Zeitpunkten verwendet werden. Die Wirkung der verschiedenen Arbeitsschwierigkeitsklassen kann nicht mit Hilfe der Ist-Zeit berechnet werden, weil der Leistungsgrad viel und ganz unregelmässig von einer Minute, oder Stunde zu anderen, einem Tag zu anderen und einer Woche zur anderen schwankt. Es wäre unrichtig zu vermuten, dass der durchschnittliche Leistungsgrad in jeder Arbeitsschwierigkeitsklasse derselbe ist.

Der Inhalt der Arbeit muss ganz genau beschrieben werden. Sonst kann man nicht wissen, zu welcher Arbeit die einzelnen Ergebnisse für Zeit and Kosten gehören. Die Arbeitsverfahren müssen zuerst mit systematischer Arbeitsgestaltung standardisiert und definiert werden, und die Arbeiter müssen diese Arbeitsverfahren gelernt haben und in ihnen geübt sein. Sonst können falsche Schlussfolgerungen bei der Entscheidung nicht vermieden werden, welche Arbeitsverfahren die besten sind.

Es ist fast unmöglich, Arbeitsstudienergebnisse zu analysieren und zu vergleichen, wenn die Gelände und andere Arbeitsschwierigkeitsklassen nicht in einer gemeinsamen und internationalen Weise abgemessen, sondern nur allgemein beschrieben sind.

Die Leistung hängt hauptsächlich von dem Leistungsgrad des Arbeiters und von seinem Zeitaufwand für unnötige Elemente während der Durchführung der Arbeitsstudie ab. Die Leistung kann während einer kurzen Zeitstudie zwischen Null und einem Maximum für jeden Arbeiter in jeder Arbeitsschwierigkeitsklasse liegen. Die maximal Leistung wird durch Arbeiter, Umwelt, Schlepper, Geräte und Arbeitsverfahren begrenzt. Nur qualifizierte Arbeiter, die die standardisierten Arbeitsverfahren gelernt und geübt haben, sollten in der Arbeitsstudie für die Soll-Zeit herangezogen werden. Zur Zeit gibt es keine Möglichkeiten, die Leistungsgradbeurteilung bei Waldarbeitsstudien zu vermeiden. In der Soll-Zeit kann man nicht irgendeine Erholungszeit akzeptieren, sondern nur die für die Aufgabe notwendige Erholungszeit.

Nur mit Hilfe der Soll-Zeiten ist es möglich, das Beste von alternativen Arbeitsverfahren zu wählen. Nur die berechneten Soll-Zeiten machen es möglich, zu beurteilen, ob eine durchschnittliche Leistung hoch oder niedrig ist. Eine niedrige Leistung bedeutet, dass die Arbeiter mehr Ausbildung, Übung und Motivation brauchen.

Eine kurze Zeitstudie begrenzt die Verwendungsmöglichkeiten der Arbeitsstudienergebnisse. Im Laufe einer Woche kann man Soll-Zeiten für einzelne Arbeitselemente ermitteln. Um Auskunft über solche Grossunfälle und grosse Reparaturen zu bekommen, die selten vorkommen, braucht man Arbeitsstatistiken für mehrere Jahre, um richtige Schlussfolgerungen ziehen zu können.

Zur Zeit besteht ein offensichtliches Bedürfnis nach IUFRO-Empfehlungen für internationale forstliche Arbeitsstudienbegriffe mit Definitionen, die bearbeitet und veröffentlicht werden müssten. Als Grundlage dafür könnten die Begriffe und Definitionen der Forestry Commission in Grossbritannien und des Kuratoriums für Waldarbeit und Forsttechnik in der Bundesrepublik Deutschland dienen. Die nordischen NSR-Begriffe umfassen nur Ist-Zeiten. Deswegen kann man mit diesen Zeitbegriffen leider nur Arbeiter, jedoch keine Arbeitsverfahren, Geräte oder Machinen miteinander vergleichen.

LITERATURE CITED

Appelroth, S-E. 1980. Comparability of work study results. p. 414-419 *in* Proceedings of the IUFRO Symposium on Stand Establishment Techniques and Technology, Moscow and Riga, September 1979, Moscow.

Appelroth, S-E. 1982a. Tidsbehovet och prestationen vid manuell plantering av täckrotsplantor efter maskinell markberedning. Summary: Time Required for and Performance Rate in Manual Planting of Containerized Nursery Stock after Mechanical Site Preparation. Metsäntutkimuslaitoksen tiedonantoja 60, Helsinki, 306 p.

Appelroth, S-E. 1982b. Recommendations for collecting data and presenting results of time studies on silvicultural operations. Institutt Forestalia Fennica, **Folia Forestalia** 539, 27 p.

Backhaus, G. 1984. p.9-12 *in* Beurteilen von Leistungen bei verschiedenen Waldarbeiten. Kuratorium für Waldarbeit und Forsttechnik IY6050EX.

Berg, S. 1982. Terrängstypschema för skogsarbeten. Forskningsstiftelsen Skogsarbeten, Stockholm, 28 p.

Böhrs, H. 1959. Normalleistung und Erholungszuschlag in der Vorgabezeit. Carl Hanser Verlag, München, 182 p.

British Standards 1969. The Glossary of Terms in Work Studies. BS 3138. British Standards Institution, London.

Eriksson, T., Nilsson, G., and Skraamo, G. 1978. The inter-Nordic project of forest terrain and machines in 1972-1975. **Acta Forestalia Fennica** 164, 60 p.

Forestry Commission 1978. Standard Time Tables and Output Guides. Forestry Commission, Her Majesty's Stationery Office, London, Booklet No. 45, 371 p.

Häggblom, R. and Kaila, R. 1982. Metsänistutuksen ajanmenekkisuhteet. Abstract: Time expenditure on manual tree planting. **Metsätehon katsaus** 8, Helsinki, 4 p.

Heidersdorf, E. and Folkema, M.P. 1976. Shift level availability and productivity: manual for collecting and recording field data. Forest Engineering Research Institute of Canada, Pointe Claire, Quebec, 14 p.

KWF 1964. Guides to work study in forest operations. Mitteilungen des KWF, Band IIIa. Kuratorium für Waldarbeit und Forsttechnik, 6079 Buchschlag bei Frankfurt/Main, 46 p.

KWF 1976-1985. Methodenlehre des Arbeitsstudiums. Teil 1, Grundlagen 1984, Teil 2 Datenermittlung 1978, Teil 3 Kostenrechnung, Arbeitsgestaltung 1985, Teil 4 Anforderungsermittlung (Arbeitsbewertung) 1977, Teil 5 Lohndifferenzierung 1977, Teil 6 Arbeitsunterweisung 1976. REFA, Carl Hanser Verlag, Darmstadt.

Löffler, H. 1984. Terrain classification for forestry. Final report to the joint FAO/ECE/ILO Committee on Forest Working Techniques and Training of Forest Workers. TIM/EFC/WP.1/R.51. Geneva. 46 p.

Makkonen, O. 1954. Metsätöiden vertailevan aikatutkimuksen periaate. Summary: The principle of comparative time studies in forest work. **Acta Forestalia Fennica** 61(14):1-18.

Mellgren, P.G. 1980. Terrain classification for Canadian forestry. Canadian Pulp and Paper Association. Montreal. 13 p.

Nguyen, V.L. 1982. Kriterien zur Feststellung von Erholzeiten bei der Holzernte nach den EST-Standardarbeitsverfahren. Mitteilungen der Forstlichen Versuchs- und Forschungsanstalt Baden-Württemberg 100. 143 p.

Norsk Institut Skogforsk. 1978. Nordisk avtale om skoglig arbeidsstudienomenklatur (Forest Work Study Nomenclature). Nordiska Skogsarbetsstudiernas Råda. Norwegian Forest Research Institute. Ås. 130 p.

REFA 1984. Anleitung für forstliche Arbeitsstudien. Datenermittlung. Arbeitsgestaltung. REFA. Fachausschuss Forstwirtschaft und Kuratorium für Waldarbeit und Forsttechnik. REFA. Verband für Arbeitsstudien und Betriebsorganisation e.V., Darmstadt Buchschlag. 209 p.

Rowan, A.A. 1977. Terrain classification. Forestry Commission. Her Majesty's Stationery Office. London. Forest Record 114. 23 p.

Wittering, W.O. 1973. Work study in forestry. Forestry Commission. Her Majesty's Stationery Office. London. Bulletin 47. 100 p.

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APPENDICES

APPENDIX A. The Technical Program (original)

INTERNATIONAL UNION OF FORESTRY RESEARCH ORGANIZATIONS

Symposium on the Equipment/Silviculture Interface in Stand Establishment Research and Operations

Jasper Park Lodge, Jasper, Alberta, Canada

28 September – 03 October 1985

Saturday, 28 September

18:00 (approx.)	Bus from Calgary arrives
18:00 – 18:30	Hotel registration
19:00 – 21:00	Supper
20:00 – 22:00	Symposium registration
21:00 – 22:00	Meeting for speakers and session chairmen

Sunday, 29 September

08:00 – 10:30	Symposium registration

Start of Symposium – L. F. Riley, Symposium Chairman

08:00 – 09:00	Opening ceremonies – Welcome by dignitaries and officials – Keynote address Jean Claude Mercier Associate Deputy Minister Canadian Forestry Service

Session I – Engineering/Biological/Operational Interactions
R. G. Brown – Session Chairman

09:00	Biological Knowledge Needed for the Development of Silvicultural Equipment – P–O. Bäckström
09:40	Coffee
10:00	The Development of Products for the 1990s with Experience from the 1970s – M. Kohonen
10:40	Choosing the Best Silvicultural Tool for the Job – J. C. Wright
11:20	Development of Silvicultural Equipment in New Zealand – E. G. Mason and J. B. Siviter
12:00	Session I ends
12:00 – 13:30	Lunch

Session II – Equipment/Soil–Site Interactions
A. D. Kiil – Session Chairman

13:30	Compaction by Logging and Site Preparation Equipment: Effects on Seedling Growth on Four Soil Types in West-central Alberta – I. G. W. Corns
14:10	Site Irregularities and Their Effect on Prime Mover and Silvicultural Equipment Operation – J. N. Wilson
14:50	Coffee
15:10	Paper to be named from All–Union Research Institute of Silviculture and Mechanization of Forestry – USSR [This did not materialize]
15:50	Prime Movers and Their Required Characteristics for Silvicultural Work – M. Ryans
16:30	Voluntary Papers
17:00	Session II ends
18:30	Barbecue Supper

Monday, 30 September

Field Tour I

07:00	Breakfast
08:00	Bus departs from Jasper Park Lodge
18:00	Bus returns to Jasper Park Lodge Supper as desired
20:00	Informal show–and–tell period

Tuesday, 01 October

Session III – Silvicultural Prescriptions
S. Ferdinand – Session Chairman

08:00	Silvicultural Prescriptions for Stand Establishment: Biological Considerations – R. F. Sutton
	Application to Silvicultural Decision–making in British Columbia – R. N. Green
09:20	Paper to be named from Czechoslovakian Research Station – CSSR [This did not materialize]
10:00	Coffee
10:20	Scarification Requirements for Regenerating Paper Birch (**Betula papyrifera** Marsh.) under Shelterwood – D. A. Perala
11:00	Norway spruce (**Picea abies** [L.] Karst.) in the Federal State of Rheinland–Pfalz: Silvicultural Prescriptions and Stand Establishment Technique – F. Esser

11:40	Voluntary Papers
12:00	Session III ends
12:00 – 13:30	Lunch

Session IV – Work Study Technique
C. R. Smith – Session Chairman

13:30	Work Study Techniques Employed in the United Kingdom and Their Application in the Evaluation of Silvicultural Equipment – R. A. Farmer
14:10	Modern Work Study and Data Collection Techniques – J. T. Clausen
14:50	Coffee
15:10	Work Study Techniques Employed at Sweden's Forest Operations Institute with Application in the Evaluation of Scarification and Planting Machines – S. Berg
15:50	The Analysis and Interpretation of Forest Work Study Results – S–E. Appelroth
16:30	Voluntary Papers
17:00	Session IV ends
18:00	Reception
19:00	Banquet – Guest Speaker, Rory Flanagan, Superintendent (retired), Jasper National Park

Thursday, 03 October

08:30	IUFRO Working Party business meeting for all delegates
09:30	Business meeting ends
10:00	Trip to Jasper Tramway and shopping in Jasper (lunch included)
14:00	Bus leaves for Calgary

APPENDIX B. Registration List

NAME	AFFILIATION	COUNTRY
Appelroth, Sven–Eric (Dr.)*	Finnish Forest Research Institute	Finland
Bäckström, Per–Ove (Prof.)*	Swedish University of Agricultural Sciences	Sweden
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